THIRD YEAR COURSES CATALOG

Academic year 2023-2024

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CIVIL ENGINEERING AND TRANSPORTATION MAJOR (CVT)

3CV1010 – Discovery of the Aeronautics, Space and Transport activity sectors

Instructors : **Ronan Vicquelin**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **70**
On-site hours (HPE) : **42,00**

Description

It is essential to provide a strong culture for third year engineering students on the sectors of activity for which the Aeronautics, Space and Transport degree is intended. The scientific, technical, socio-economic, environmental and safety issues are essential in these fields without forgetting the constraints of industrialisation and operation. In order to become fully aware of these stakes around a transport system, several activities are proposed in close proximity to the industrial environment.

Quarter number

SD9, SG10, SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Company visits over 8-10 dedicated days.

Thematic days. For example: Research Day (visit to a research laboratory, testimonials from alumni, round table), visit to the Air and Space Museum at Le Bourget with Dassault-Aviation engineers.

Case studies.

Conferences and round tables.

Grading

The evaluation is done on a "pass or fail" basis. Consideration is given to:

attendance - mandatory and active - at each of the events

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

Identify the stakes, evolutions, innovations and technological breakthroughs in progress in various sectors of activity related to aeronautics, space and transport.
Understand the complexity of a transport system subject to multiple constraints and the interactions between the various engineering professions.
Understanding the value chain in a company
To mature his professional project in the perspective of his final internship and his first job.

3CV1020 – Introduction to the AEC sector

Instructors : **Christian Cremona, Pierre JEHEL**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **30,00**

Description

The AEC sector covers a wide spectrum of activities ranging from the development of cities (living spaces) to the development of transportation hubs (Grand Paris Express stations), the construction of buildings (residential, office towers), the construction of major infrastructures (tunnels, bridges, dams), from the renovation of existing structures to the realization of new constructions.

This course offers the possibility to visit large construction and urban development sites. The conferences offered during theses visits show the major transformations under way in the AEC sector, in particular the global changes due to the development of digital technologies, climate change, social transformations (urbanization, resilience...).

Quarter number

SD9, SG10

Prerequisites (in terms of CS courses)

none

Syllabus

The discovery of the AEC sector will be done through two types of activities:

- A forum in September where industrial partners present their activities and fields of expertise
- A series of visits.

Grading

Assessment on a “pass or fail” principle.
Attending the Forum with the industrial partners is compulsory.
Participation in the 4-day study trip is compulsory.
A minimum of 3 visits have to be done in addition to the 4-day study trip in France.

Resources

The visits take place in the Greater Paris area and during of a 4-day study trip in a large city in France different other than Paris in October.
A complete kit of PPE (personal protective equipment) is provided to each student.

Learning outcomes covered on the course

In this course, students will acquire a culture of the AEC sector through practice.
In addition, students will be able to:

- Understand and detect the major transformations underway in the construction and city sectors
- Communicate on these major transformations
- Understand the variety of actors and activities in the AEC sector.
- Recognize the main socio-economic players in the sector.

3CV1030 – Applied Fluid Mechanics

Instructors : **Franck Richecoeur**
Department : **DOMINANTE - CONSTRUCTION VILLE TRANSPORTS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The course has two objectives that can be formulated in terms of general skills:

- To know how to model a general fluid mechanics problem in order to evaluate the performance of a system
- To interpret, analyze and synthesize a scientific document related to fluid mechanics.

The course aims to make students autonomous in modeling and calculating orders of magnitude associated with incompressible fluid mechanics problems. This work is feasible with a good knowledge of the fundamental equations of fluid mechanics, the laws and principles of thermodynamics, and balance theorems. The course and the practical exercises covered aim at acquiring a methodology to put into equations a fluid system and then to formulate the right hypotheses to simplify and calculate the quantities associated with the system such as forces, powers, speeds, pressures involved. With a little practice, students will be able to understand the problems dealt with and the methods used in simple research papers.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Content to be known and used (a set of video and written materials associated with a collection of exercises is available to get up to speed before the course):

Definitions:
- Law of perfect gases
- Reynolds number
- Incompressible fluid
- Stationary flow
- Mixing fractions
- Stresses in a fluid and parietal stress
- Material volume, arbitrary volume
- Material derivative
- One-dimensional approximation
- Pi (or Vashy-Buckingham) theorem
- Singular and regular pressure losses

Local equations :
- Transport theorem in one dimension
- Continuity equation : mass balance
- Navier-Stokes equations : momentum balance
- Conservation of energy equation

Integral equations and theorems :
- Bernoulli's theorem
- Mechanical energy theorem
- Momentum theorem

Syllabus

The course does not introduce or demonstrate any new equations, it aims at confronting the students with several situations characteristic of fluid problems encountered in the transportation, energy and construction sectors.
Each session consists of a 1.5 hour lecture where a new problem will be tackled, i.e. a situation where the same methodology is applied but where the assumptions necessary for the solution vary. Among other things, we will be confronted with two-dimensional laminar flows, flows in ducts, wind tunnels for models, premixed laminar flames, free surface hydraulic flows, safety systems for smoke evacuation, multi-species flows.
In the second part, and between each session, the students must finish the problems and exercises started in class, then work in groups of 3 to build 2 deliverables to be handed in at the time of the final exam. At least 30 minutes of small group discussions with the teacher are offered each week to accompany the progress of the work and answer questions.
The course is based on a body of knowledge that must be refreshed, consolidated or acquired independently before and during the course.

Class components (lecture, labs, etc.)

The proposed method is globally inductive: the skills are built from a series of applications. This allows the students to acquire methods of modeling, analysing and solving fluid mechanics problems, and to question and reinforce their mastery of the fundamental equations of fluid mechanics. Each session is built in two parts: a first one, called demonstrative, where the teacher exposes a method and solves problems, and a second one, called active, where the students have to produce contents to appropriate the methodology.

Grading

The evaluation is based on two works due on the same day:

- a two-hour written exam presenting a fluid system whose properties are to be calculated without the aid of intermediate questions
- a written document presenting the content of a scientific or technical article chosen during the session

Course support, bibliography

- Ronald L. Panton, "Incompressible Flow", Wiley, Fourth Edition, 2013, ISBN:1-118-01343-3
- Chaudhry, M Hanif. "Open-Channel Flow", Springer, Second edition, 2008. ISBN 978-0-387-68648-6

Resources

- memory cards containing all the equations needed to model and solve a fluid mechanics problem,
- short videos illustrating properties or phenomena related to incompressible flows,
- self-assessment MCQs
- a course handout detailing all the fundamental equations

Learning outcomes covered on the course

At the end of this education, the student will have acquired several levels of skills and will be able to :

Level 1 (prerequisites): Knowledge

- Provide definitions
- Naming certain types of flows
- Know how to manipulate local equations of balance: switch from vector to scalar writing, write the material derivative,
- Write macroscopic balances of mass, momentum, and energy for simple cases
- Principles of thermodynamics for open systems,
- Calculation of the energy and entropy of a single flow
- Applying Bernoulli's theorem to simple situations

Level 2 (prerequisites): Understanding

- Reformulate the hypotheses of a statement in physical and mathematical terms (laminarity, stationary, incompressible, isobaric, etc.),
- Give phenomenological explanations of certain flows based on observations,
- Explain the origin of the fundamental equations
- Give the meaning of terms in the equations
- Carry out calculations from balance sheets in simple configurations
-

Level 3: Application / Methodology :

- Putting into equations a macroscopic fluid system
- Explain the physical properties of flows encountered in transportation and construction
- Calculate the characteristic quantities of several families of flows.

Level 4: Analysis and critical evaluation

- Reformulate the content of a technical or scientific document based on the equations of fluid mechanics

Description of the skills acquired at the end of the course

- Formalize and solve a fluid mechanics problem arising from industrial applications
- Analyse and reformulate scientific and technical documents related to flows

3CV1050 – Structural mechanics

Instructors : **Pierre JEHEL**
Department : **DOMINANTE - CONSTRUCTION VILLE TRANSPORTS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Modern structural mechanics is based on the principles of Newton's mechanics, the work of illustrious scientists of the 18th century (Euler, Bernoulli, Lagrange ...), but also on works developed in the 19th century (Kirchhoff, Love ...) and then in the 20th century (Timoshenko, Mindlin, Reissner…). It is a discipline which is the basis of computational simulation tools and of the construction processes used in engineering for the design, production, and maintenance of transport vehicles (planes, boats, cars, spacecrafts), infrastructures for transportation or energy (bridges, tunnels, nuclear power plants, dams), buildings (including high-rise buildings).

Today, vehicles and structures are designed, built, and operated with the need for optimizing the resources mobilized, for ensuring the safety of people and goods, for providing ever more advanced functions (aesthetics, resilience of societies). Structural mechanics occupies a central place in this search for performance. On the one hand, its developments must be extended to represent with increasing accuracy the phenomena that originate in the behaviors of constituent materials pushed to their capacity limits, as well as in bold geometries, highly slender for example. On the other hand, the modeling assumptions and the limits of the theories implemented in computer programs must be mastered and criticized to reach reliable simulation results.

The main objective of the course is to make the students autonomous in the modeling of a problem of structural mechanics and in the analytical calculation of the orders of magnitude for achieving a first estimation of the performance of a structure (circulation of forces, displacements, stresses and strains). The course makes possible to acquire a methodology allowing to put a structural system into equations within the limits of analytical calculation (without using numerical simulation) and gives the possibility to each student to go as far as possible. The course also introduces fundamental concepts on which structural calculation software is based and therefore develops a critical approach to using software.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Content to know and be able to use (a set of video and written materials is available to upgrade before the course):

Green-Lagrange deformation tensor
- Deformable solids
- Lagrangian approach
- Transformation gradient
- Green-Lagrange tensor
- Small deformations

Cauchy stress tensor
- Conservation of momentum
- Mechanical actions
- Conservation of angular momentum
- Modeling of internal forces
- Stress tensor: definition and properties

Material behavior
- Linear isotropic elastic behavior

Internal forces in a beam

- Introduction to the beam model
- Assumptions on the stress tensor
- Resultant and moment of internal forces
- Associated equilibrium equations: global approach
- Associated equilibrium equations: local approach

Beam model

- Approximate displacement
- Euler-Bernoulli hypothesis

Syllabus

1. Statics of beams (tracks A and B)

- Forces in beams
- Normal stress field
- Equilibrium equations for straight and curved beams
- Supports and boundary conditions, notions of statically determinate or indeterminate structure
- Forces circulation in lattice beams

2. Beams kinematics; beams behavior laws (tracks A and B)

- Kinematics: Euler-Bernoulli and Timoshenko assumptions
- Geometric properties of beams sections
- Propriétés géométriques des sections de poutres
- Lois de comportement des sections de poutres
- Champs de contraintes normales
- Champs de contraintes tangentielles

3. Beams dynamics (track A)

3. Beams dynamics (track B)

- Comparison between Euler-Bernoulli and Timoshenko kinematics
- Tangential stresses in thin sections
- Torsion

4. Displacements in beams (tracks A and B)

- Bertrand de Fontviolant equation (*)
- Rayleigh-Ritz method
- Finite elements formulation
- Resolution of statically indeterminate systems
- Continuous beam

(*) http://archives-histoire.centraliens.net/pdfs/revues/rev43.pdf

5. Elastic buckling (tracks A and B)

- Equilibrium equation in the deformed configuration
- Geometric stiffness,
- Buckling length
- Compressive limit loading
- Design

6. Plastic yielding of beams systems (tracks A and B)

- Material elasto-plastic behavior
- Plastic moment, plastic hinge
- Coupling between normal force and bending moment
- Plastic collapse
- Design

Class components (lecture, labs, etc.)

Theoretical presentations are kept to a minimum.
Concepts are introduced by solving actual problems.

Grading

Each student of the course analyzes an existing or futuristic structure of their choice in the light of the concepts covered in the course. This work is presented in 5 slides accompanied by a 5-page (maximum) calculation note. Calculations must be based on analytical methods; an Excel table or a Python notebook can be used for some tedious calculations by hand.

Are expected:
- A mechanical model of the structure or a part of a structure with justification of the modeling assumptions; the model must allow the study without resorting to computational simulation (3 points).
- A model of loading and of boundary conditions sufficiently simple for analytical calculations but coherent with one of the functions the structure must fulfill (3 points).
- A justification of the geometry of the structure from the analysis of the statics forces circulation (3 points).
- A calculation of the stresses at the level of an assembly between two structural elements or in a critical zone (3 points).
- An estimate of the maximum displacements in the case of a homogeneous isotropic elastic material (3 points).
- Plastic calculation of a critical zone and / or elastic instability (3 points).
- Quality of rendering (2 points).

For each of these criteria, the acquisition of several skill levels is assessed:
1. Level 1 - Knowledge. The student is able to analyze a structure by placing it within the framework of a problem treated in class (knowledge of methods and general principles).
2. Level 2 - Comprehension. The student is able to analyze a structure by applying the methods of the course to relatively new situations in relation to the problems studied in class.
3. Level 3 - Proficiency. The student demonstrates the ability to develop the general principles and methods of the course to go beyond the examples covered in class possibly based on scientific papers.

Course support, bibliography

Bauchau O.A., Craig J.I. Structural Analysis - With Applications to Aerospace Structures. Springer, 2009.
De Buhan P. Plasticité et calcul à la rupture. Presses de l'ENPC, 2007.
Puel G., Hamon A.-L. Mécanique pour l'ingénieur - Milieux continus solides et fluides, systèmes multicorps, structures. Dunod, 2021.
Puel G., Barbarulo A. Mécanique des milieux continus. Polycopié du cours 1EL5000, CentraleSupélec, 2021.
Timoshenko S.P., Gere J.M. Theory of elastic stability. McGraw-Hill, 1961.
Timoshenko S.P., Woinowsky-Krieger S. Theory of plates and shells. McGraw-Hill, 1959.

Resources

The first 2 sessions are common.
The last 4 sessions are divided into 2 tracks chosen by the students:

- Track A = advanced course for students who already have a good knowledge in structural mechanics.
- Track B = progressive course where time is devoted to learning the basic concepts of structural mechanics.

Between two course sessions, students work on an individual project that will be evaluated at the end of the course. Office hours are held by the teachers to answer the questions of the students.

Learning outcomes covered on the course

At the end of the course, the students:
- Know the main theories and methods for the static analysis of common structural elements
- Have a good understanding of the physical mechanisms that govern the behavior of common structural elements
- Know orders of magnitude for the pre-design of common structures
- Are able to set up an engineering approach for the pre-design of common structures.

3CV1060 – Materials engineering

Instructors : **Véronique Aubin**
Department : **DOMINANTE - CONSTRUCTION VILLE TRANSPORTS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Structures used in transport and construction must meet two challenges: performance and safety. The materials used in these structures must be capable of meeting these objectives as effectively as possible. To achieve this, they must respond to the stresses exerted on the various components of these structures: mechanical and/or environmental stresses, temperature conditions.
The aim of this course is to enable students to understand and identify the physical phenomena at work according to the families of materials and stresses, and to know how to choose the right material.

Quarter number

SD9

Prerequisites (in terms of CS courses)

The basic knowledge of continuum mechanics is to be acquired before the beginning of the course thanks to the leveling documents provided.

Syllabus

1. Elasticity, importance of the atomic nature of materials.
2. Composite materials and linear homogenization
3. Plastic deformation mechanisms
4. Damage and fracture. How to predict material failure?
5. Intense loadings (temperature, environment)

Class components (lecture, labs, etc.)

Grading

Individual knowledge test
Final group assessment

Course support, bibliography

- Engineering Materials, M.F. Ashby et D.R.H. Jones, ED. Dunod
- Mechanics of solid materials, J. Lemaître et J.L. Chaboche, Cambridge university press, 1994.
- Continuum mechanics, Puel G, CentraleSupélec

Resources

Learning outcomes covered on the course

At the end of this course, students will be able to :
- describe the physical phenomena responsible for a material's performance in a given application
- discuss the beneficial or aggravating effects of intrinsic and extrinsic effects (nature of the material, production process, stresses, environment, etc.) on the desired performance or safety of the component studied
- choose a family of materials for a given application
- dimension a component according to standard criteria (rigidity, yield strength, toughness, etc.)

Description of the skills acquired at the end of the course

3CV1070 – Computational Fluid Dynamics

Instructors : **Aymeric Vie, Ronan Vicquelin**
Department : **DOMINANTE - CONSTRUCTION VILLE TRANSPORTS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Numerical simulation in fluid mechanics is today a tool widely used in industry for design and proof of concept. These numerical simulations are based on the one hand on a physical model, and on the other hand on a discrete representation of this model, which leads to numerical errors. It is therefore necessary to be able to control these numerical errors so that the simulation is faithful to the model.

The objective of this course is to present a set of numerical methods necessary to solve the Navier-Stokes (NS) equations governing the dynamics of a fluid, and to put the students in the situation of building themselves a solver allowing them to solve these equations in the case of a given physical problem. Among a set of proposed methods, they will have to choose themselves the appropriate methods, and be able to explain the advantages and disadvantages of the choices they will have made. The different theoretical aspects will be presented through simple fluid mechanics problems, allowing to isolate one or two elements necessary to solve the NS equations. A second practical part will be dedicated to the resolution of a fluid flow requiring to use all the elements of the course, on the one hand using a code developed by the students, and on the other hand using an existing solver (Ansys Fluent).

Quarter number

SD9

Prerequisites (in terms of CS courses)

none

Syllabus

- The course is divided into three parts:
- A first individual part:
  - TD 1&2(4h30): Hyperbolic and parabolic equations: dispersion of a scalar in Taylor-Green vortices, illustrating thermal mixing in a room by a forced flow.

- A second part of project type in groups of two or three students, on the study of the flow around an obstacle with Ansys Fluent, illustrating the external aerodynamics of a building:
  -TD 2&3 (4h30): getting to grips with Ansys Fluent on the simulation of the flow behind a cylinder.

- A third part of project type in groups of two or three students, on the study of the flow in a channel to quantify the pressure losses, with Ansys Fluent and the code developed by the students
  -TD4&5 (6h): flow in a channel.

- A fourth part of project type in groups of two or three students, on the study of air ventilation in a room:
  -TD6 (3h): velocity field with Ansys Fluent.
  -TD7 (3h): velocity field with the code developed by the students.
  -TD8 (3h): addition of a CO_2 production and optimization of the ventilation system.

Class components (lecture, labs, etc.)

- The course will be conducted in TD only.

Grading

The final grade N will be broken down as follows:

- 1/3 based on the first individual project: a report to be handed in before session 4 of the course, with the computational codes.
- 1/3 based on the second project (in group), evaluated on a defense to be recorded under teams and returned before session 7.
- 1/3 based on the fourth project (in group), evaluated on a defense to be recorded in teams and due three weeks after the last session.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

Choose the numerical method best suited to the targeted problem
Characterize the associated numerical error
Ensure the numerical convergence of their simulations
Numerically solving Navier-Stoke equations

3CV1080 – Numerical methods in solid mechanics

Instructors : **Andrea Barbarulo**
Department : **DOMINANTE - CONSTRUCTION VILLE TRANSPORTS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The finite element method is a method of choice for scientific computation applied to engineering sciences. The main objective of the course is to teach the skills needed to use this method for the analysis of problems in solid mechanics. Students will learn the basic principles of the method and will be trained in the development of appropriate finite element models and the interpretation of numerical results. A second objective is to familiarize the students with the Comsol Multiphysics software. The acquired knowledge will be useful for the supervision of design projects.

Quarter number

SD9

Prerequisites (in terms of CS courses)

none

Syllabus

The teaching will be entirely carried out in reverse class. The students will have at their disposal a handout.

The course is divided into two parts:

- A first individual "theoretical" part mixing analytical and numerical implementations using the Comsol Multiphysics software:

- TD 1 (3h) : Strong and weak formulations

- TD 2 (3h): Galerkin's method: 1D implementation

- TD 3 (3h): 2D and 3D Finite Elements

- TD 4 (3h): Isoparametric Elements, Quadrature Methods

- A second part of the project type in groups of two or three students :

- 4 sessions of 3 hours on the implementation using the Comsol Multiphysics software of a project dealing with a problem of solid mechanics.

Class components (lecture, labs, etc.)

Teaching will be carried out only in TD (reverse class).

Grading

The final mark N will be broken down as follows:
- 50% based on the individual "theoretical" part: this will include a written exam mark (1h30), and a computer practical exam mark (1h30), each counting for 50% of this theoretical mark

- 50% based on the "practical" part in groups: students will have to record a video synthesizing the choices of simulations and their results, based on a presentation support. This presentation, the video, and the students' simulation files should be given to the teachers.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- Establish the weak formulation of any problem at the boundaries

- Write the corresponding finite element formulation

- Develop the model in finite element simulation software, and solve the problem

- Analyze the accuracy of the digital solution

3CV1110 – Product Life-cycle Managnement

Instructors : **Pascal MORENTON**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

To present Product Life-cycle Management and its strategic interest for the company, to give elements of context that led to its emergence in all sectors of activity,

Present the key points of a PLM strategy from the perspective of organizations, processes, tools, methodologies, Have the students deal with an exemplary case study derived from an industrial issue that highlights some of these key points and some key concepts or processes of a PLM approach, namely: part, bill of material, change management, configuration,

Identify the key points for integrating Computer Aided Design tools in a PLM approach.

Quarter number SG10

Prerequisites (in terms of CS courses) None

Syllabus

Introduction to PLM; testimony and feedback from Dassault Aviation in this field,
Presentation of the proposed case study
parts, bills of material and routings for a product,
Product Change Management
Use of the digital mock-up in a "PLM" approach

Class components (lecture, labs, etc.)

After a short introduction, the course will be structured around a case study that will form the "red thread" of the activity. This study is structured in 3 parts

Range and "business" viewpoints on a product structure,
Product change management,
Use of a digital mock-up in "PLM" context.

Theoretical and practical presentations will be made "on the fly" to provide the knowledge and skills needed to complete the three parts.
The work will be carried out in groups.

Grading

The course will be evaluated by :

participation in the activities proposed as part of the course,
evaluation of the work carried out in the case study
Relevance of the work carried out and good understanding of the key concepts introduced,
quality of the deliverables,
quality of the oral defense.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- Identify the key points of a mastered PLM approach,
- Evaluate the level of complexity related to the management of a configured digital mock-up,
- To implement the foundations of a "business" nomenclature management,
- Have a minimum practice of a 3D CAD modeler

3CV1120 – Digital twin and Integrated engineering

Instructors : **Pierre JEHEL**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **24,00**

Description

The digital twin of a structure (building, infrastructure) contains information on the physical system it represents (geometry, material properties, networks, etc.) as well as - in the most advanced cases - algorithms for processing this information (learning machine, AI, optimization, etc.). It is a technological tool that makes it possible to improve the performance of the object it represents, to anticipate changes throughout its life cycle, to plan production or maintenance activities, to make them change the design... within a framework constrained by economic, social, and environmental performance objectives forcing different actors of the value chain to interact and work in an integrated way.

In the construction sector, the concept is emerging. Digital modeling and simulation tools are used from the work of the architect through the design, construction, operation, and maintenance of structure to their dismantling. To consider the work from the perspective of its life cycle, the integration of these tools in a digital twin is a current topic of development and research.

The course offers 3 different tracks and the students have to choose one of them. For each of these tracks, the objective is to put the students in a situation of user of one or more digital tools to act in a specific phase of the life cycle of a structure: design of the structure (track A), synthesis of the design at the interface between different engineering teams (track B), building in operation (track C).

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

Students have the choice between 3 tracks:

- Track A : Design a a structure that meets a given set of specification. Software used: Pythagore (finite elements).
- Track B : Design of a railway system. Example of software used: Revit, Novapoint Railway, Trimble Connect collaborative platform.
- Track C : Evolution of uses in a building in operation. Example of software used: BIMVision.

Class components (lecture, labs, etc.)

Team work.

Grading

Grading will take the form of a presentation to a jury at the end of the course.

Learning outcomes covered on the course

After this course, the student will be able to:
- Understand how to solve an engineering problem in a digital environment.
- Make the right working and modeling hypotheses based on the digital tools available.
- Design and test different scenarios.
- Criticize the numerical results obtained and choose a solution.

3CV1130 – Energy transition: challenges of the transport sector

Instructors : **Ronan Vicquelin, Didier Hauglustaine**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

In response to the climate emergency, the transport sector is now committed to an accelerated decarbonization strategy, which sets ambitious targets for reducing CO2 emissions by 2050. This strategy is based on the use of alternative fuels with a low carbon footprint and intensified efforts to improve the energy efficiency of aircraft and their operations. To date, air transport remains almost exclusively dependent on fossil fuels and therefore contributes to global warming through the carbon dioxide (CO2) emissions resulting from the combustion of this fuel. However, CO2 is not the only contributor to the global climate impact of air transport. The release of chemical species other than CO2, and in particular nitrogen oxides (NOx), water vapor and volatile and non-volatile particles, also generate perturbations of the terrestrial radiation balance through physico-chemical processes such as the formation of contrails and induced cirrus clouds, interactions with clouds or the formation of ground-level ozone.

In this course we will give the keys to better understand the environmental issues related to the transport sector with a particular attention to air transport which is at the heart of many debates. This understanding will first require a better understanding of the physical processes governing the climate system, the biogeochemical cycles of carbon and nitrogen, and the chemistry of the atmosphere and the fate of pollutants in the air. The impact of transport on climate will then be analyzed and put into the perspective of global climate change. To do so, several metrics will have to be introduced to quantify the relative role of transport and the different agents contributing to climate change. These different metrics (e.g., radiative forcings, temperature variations, global warming potentials) will be presented and compared. In addition, the concept of Life Cycle Assessment (LCA) will be introduced and applied to the transportation sector.

Quarter number

SG10

Prerequisites (in terms of CS courses)

aucun

Class components (lecture, labs, etc.)

The course will be organized into a series of seven 1.5 hour lectures covering climate, the carbon cycle, air pollution, climate impacts of transportation and aviation in particular, metrics used to quantify transportation climate disruption. In addition, a 3-hour session will focus on Life Cycle Assessment (LCA) with applications (TD) to the transportation field.

Grading

The evaluation will take the form of an MCQ.

Learning outcomes covered on the course

- General knowledge of the climate system, the carbon cycle and air pollution.
- Global warming issues and how to respond to controversial issues.
- Impact of transportation and aviation emissions in particular on the environment.
- Roles of CO2 and other agents in climate disruption.
- Metrics to quantify the impact of a sector of activity on the climate, application to the case of aviation.
- Life Cycle Analysis applied to the transportation sector

3CV2010 – Earth system

Instructors : **Pierre JEHEL, Didier Clouteau**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **18,00**

Description

This course aims to provide the scientific basis for understanding the Earth system (climate, geology, oceans) and the impact of human activity on it.

Quarter number

SD9

Prerequisites (in terms of CS courses)

none

Syllabus

Course 1 (3h): Formation of the Earth system
Formation and evolution of the Earth's envelopes (atmosphere, ocean, crust, mantle) over time. Initial accretion, formation and evolution of the crust, origin of water on Earth, broad outlines of the appearance and evolution of living things, stages of formation of the atmosphere, major crises.

Course 2 (3h): Continental surfaces
Place and characteristics of continental surfaces in the long-term evolution of the Earth system. Lithological diversity of continental surfaces, rock cycles, renewal of these surfaces and creation of relief, the role of weathering and erosion, balance of exchanges with the atmosphere, geological storage of carbon.

Lecture 3 (3h): the climate system
Components of the climate system, time scales, forcings, their interactions, radiation balance, GHG, greenhouse effect, notion of imbalance, observation of current climate change (SR 1.5°C).

Course 4 (3h): Ocean and Atmosphere Dynamics
Energy transport and fluid envelope dynamics, Hadley convection cells, thermohaline circulation, surface circulation, role of the poles (polar amplification) SROCC (IPCC Special Report on Ocean and Cryosphere).

Course 5 (3h): Carbon cycle
The different carbon reservoirs, order of magnitude and associated time scales, the role of the biosphere, permafrost, and SRCCL (IPCC Special Report on Land Use and Climate).

Course 6 (3h): hydrogeological system
Continental hydrological cycle and water resources. Impact of recent climate change.

Grading

Continuous control in the form of multiple choice questions and reports.

Learning outcomes covered on the course

At the end of this course, students will know the main stages of the creation of our planet, the current climate system and its anthropogenic evolution, and the need to preserve and manage geological and hydrological resources.
In particular, they will be able to respond with scientific arguments to climate skeptic and creationist theories.

Description of the skills acquired at the end of the course

C3: Act, undertake, and innovate in a scientific and technological environment
"Understand and interact with specialists in earth sciences: geologists, hydrologists, climatologists"

C9: Think and act as an ethical, responsible, and honest engineer, taking into account environmental dimensions
"Be aware of the challenges of climate change and the scarcity of natural resources both in terms of reducing impacts and adapting to risks"

3CV2020 – Consruction Processes for Bridges

Instructors : **Brice Bossan, Pierre JEHEL**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **15,00**

Description

The course aims at making students understand how bridges are designed and built.

The course gives vocabulary as well as many design and pre-design elements. Using commented pictures of construction works, it describes a wide range of construction methods and processes, and it highlights the interaction between design and construction.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

Session 1 : Introduction to bridge structures, common bridges and cast-in-place concrete bridges
3h lecture

- Vocabulary
- Elements on the geometrical constraints and design of the structures
- Functions of the different equipments of the structures
- Classification of bridge structures
- Static diagrams of bridges
- Common cross sections
- Construction methods of common bridges: falsework, scaffolding

Example of the construction phasing for building a common structure from the foundations to the finishing (highway overpass).
Operation of a self-launching erection machine.

Session 2: Mixed steel-concrete bridges, prestressing
2h lecture:

- Mixed section behavior
- Design of beam bridges
- Construction: manufacturing, transportation, assembly and installation of the framework, construction of the slab (cast-in-place or prefabricated concrete elements).
- Principles of prestressing.

1h tutorial: Design exercises.

Session 3: Balanced cantilever method
2h15 lecture:

- Principle of balanced cantilever construction
- Static analysis
- Cross section, design of elements
- The different types of prestressing cables
- Common and special girder segments: functions and design.
- Stability of the girder

45 min tutorial: girder stability:

- Cast-in-place concrete method
- Examples of constructions

Session 4: Incrementally launched bridges, prefabricated bridges
3h lecture:

- Incremental launch: principles; geometric constraints; structural constraints; tendons design; the equipments (sliding bearings, pulling jacks, launching nose, casting bed on the abutment).
- Prefabricated bridges: what to prefabricate? why prefabricate? segmentation of the structure; prefabrication tools; construction methods.

Session 5: Arch bridges, cable bridges
2h lecture:

- Arch bridges: different types of arches; statics and hyperstaticity; funicular geometry; design elements; stick segment jacking / asymmetric load cases; classic and modern construction processes.
- Suspension bridges: statics, when to use them
- Cable-stayed bridge: configuration and design longitudinal / transverse direction
- Technology and behavior of the cables
- Towers and decks
- Construction (installation of the cables)
- Assembly of a suspension cable.

1h: examination.

Grading

A 1 hour-exam in the end of the last course session with questions to test your knowledge of the course and an exercice.

Learning outcomes covered on the course

After the course, the students will:

- Be able to identify the different types of bridge structure.
- Understand the structural choices made by the designers
- Know the general construction methods, their field of application and the main constraints they bring to the design of the structure
- Be able to choose between several design options
- Have the skills for "pre-designing" a common bridge structure.

3CV2030 – Reinforced concrete

Instructors : **Pierre JEHEL**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **24,00**

Description

This course teaches the design of reinforced concrete structural elements (beam and column) and of a prestressed concrete elements (beam or bridge deck).

Quarter number

SG11

Prerequisites (in terms of CS courses)

Basics of statics (forces and stresses)

Syllabus

Part 1 - Reinforced concrete

Session 1 (3h lecture):
General: Presentation of Eurocode EN 1992: general information on the rules, characteristics of concrete and steel materials, durability, service limit states, ultimate limit state, actions, combinations of actions.

Session 2 (1h lecture + 2h design tutorial):
Bending ULS: Section subjected to bending ULS, design, rectangular section.

Session 3 (1h lecture + 2h design tutorial):
Shear force ELU: Section subjected to a shear force, design, rectangular section.

Session 4 (1h30 lecture + 1h30 design tutorial):
Verification of a continuous beam in single bending SLS: verification of stress states and crack opening, verification of deformations.

Session 5 (1h30 lecture + 1h30 exam):
Design and verification of a continuous beam at ULS: reinforcement sketches, verification of end zones.

Part 2 - Prestressed concrete

Session 6 (3 h lecture):
Principle of prestressing, field of use, implementation, effect of prestressing a structure, prestressing steels, constructive provisions.

Session 7 (1h lecture + 2h design tutorial):
Pre-stress losses, justification of normal stresses and control of the cracking, bending in SLS, application to an isostatic beam.

Session 8 (2h lecture + 1h exam):
Shear force ELU, application to an isostatic beam.

Grading

- "Reinforced concrete" part: exam in the end of session 5
- "Prestressed concrete" part: exam in the end of session 8

Learning outcomes covered on the course

Part 1 - Reinforced concrete:

At the end of reinforced concrete lectures, the student will be able to:

- Use the Eurocodes for continuous beam type structures
- Design a structural element subjected to bending
- Design the reinforcement in the critical sections
- Implement passive reinforcement

Part 2 - Prestressed concrete:

At the end of the prestressed concrete lectures, the student will be able to:

- Check the geometric pre-dimensioning of a beam
- Determine the number and position of the prestressing cables
- Define the position of the cables along this beam

3CV2040 – Architectural Engineering

Instructors : **François Cointe**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **50**
On-site hours (HPE) : **48,00**

Description

Beyond the structure, it is the building envelope, combined with the technical equipment, that enables the essential functions of a building to be carried out: enclosed and covered, lighting, thermal and acoustic comfort, health and hygiene of the occupants.
The aim of this course is to present the physical phenomena that govern these exchanges between the interior and the exterior, to give the associated calculation tools, to present the construction techniques and equipment that enable these functions, and thus the comfort of the occupants, by confronting them with the contemporary concerns of sustainable development and energy savings, while inscribing them in the history of architecture and construction processes, through the analysis of numerous examples of remarkable constructions, both technically and historically.
Each course is built in triptych courses/tools/applications: historical panorama of the evolution of constructions on the chosen problematic, presentation of calculation methods, application by groups of students to a panel of selected exemplary buildings.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

1 **- Hygiene - Ventilation and air quality**

- Course: Insalubrity of housing and the fight against epidemics: hygienic designs of buildings and regulatory developments in architecture from the 18th to the 21st centuries.
- Calculation methods and regulations: regulatory ventilation rates, calculation of heat loss through ventilation, etc.
- Case study: loges des folles in La Salpétrière, Haussmann-style building on rue du pont neuf, open-air school in Suresnes, Le Corbusier's Radieusse housing estate, Max Weber Nanterre University building, mille arbres porte Maillot...

2 - Light

- Classes: Glass in facades: From bays in the masonry to curtain walls and double skins: developments in the techniques for manufacturing and using glass in facades.
- Calculation methods: sunlight measurement, daylight measurement, day and night lighting requirements.
- Case study : Pantheon in Rome, Dulwich Picture Gallery, First Leiter building, Lake shore drive building in Chicago, Lever House in New York, US consulate in Luanda, The edge Amsterdam.

3 - Building with the climate

- Course: climatic determinism in traditional and contemporary architecture: cold climate, humid tropical climate, hot and dry climate.
- Calculation methods: psychrometric diagram, Victor Olgyay's bioclimatic diagram and Givoni's bioclimatic diagram.
- Case study: the Alhambra in Granada, Ghardaïa, badgirs and canats in Yazd, New Gourna girls' school, Pearl academy of fashion in Jaipur, rectorate of Martinique, Falatow Jighiyaso Dialakoroba orphanage in Mali

4 – Acoustics

- Courses: Sound reverberation, sound quality and acoustic treatment of confined spaces, architectural design of auditoriums.
- Calculation methods: sound measurement, Sabine's formulas and acoustic regulations.
- Case Study: Abbey of the Angels in Landeda, Ircam, Philharmonie du Luxembourg, Casa Musica in Porto, Elbe Philharmonie in Hamburg

5 - Air conditioning

- Course: Evolution of air conditioning and air conditioning techniques, from the first Carrier air-conditioned printing plants to the 2226 building cooled by natural ventilation, without heating or air conditioning.
- Calculation methods: Air-conditioning heat balance, Enthalpy evolution of air-conditioning systems on the Carrier diagram
- Case Study: City of Refuge, Lever House, Arche de la Défense, France Avenue Building, 270 Aubervilliers, Sonnenschiff Fribourg, San Francisco Federal Building, 2226 in Lustenau

6 - Energy efficiency and thermal insulation

- Course: Taking into account the thermal insulation of buildings after the 1973 oil crisis, regulatory changes and their impact on architecture.
- Calculation methods: calculation of losses by facades, winter heat balance.
- Case study : Housing 5PA1 the old fountain, Mäder eco-college, green residence in Montpellier, Maison de l'île de France in the university city

7 - Positive energy building

- Courses: Evolution towards energy-producing or energy self-sufficient buildings, from the dymaxion house of Buckminster Füller in 1929 to the present day
- Problem: Solar energy and heat storage techniques.
- Case study : Alexander Pike's Autonomous House Project, Odeillo solar building, Earhtships, Bedzed, Maison de l'Île-de-France...

8 - Summary and supplements

Class components (lecture, labs, etc.)

1 - "Technical design of buildings" course (24 hours):
Each course is organised in three parts: a half-hour lecture and presentation of calculation tools, followed by direct application and group feedback by the students.
2 - "Low carbon design" project (24 hours):
The choice of projects and the assignment are based on the student's professional aspirations.
Projects are developed in teams.
8 full half-days are devoted to the project. They are supervised by professionals.

Grading

The assessment is based on a team report for the project activity, graphic elements in the form of plates accompanied by technical documents, and an individual report on a study proposed by the teacher for the course part.

Resources

Lectures and presentations of calculation methods will be recorded in the form of short half-hour video clips for all circumstances where it is not possible to attend face-to-face lectures.

A handout on "Technical design of buildings" completes the documentation provided.

Description of the skills acquired at the end of the course

C1.1: Studying a problem as a whole, the situation as a whole. Identify, formulate and analyse a problem in its scientific, economic and human dimensions.
C1.3: Solve the problem with a practice of approximation, simulation and experimentation.
C1.6: Mobilize a broad scientific and technical base in the framework of a transdisciplinary approach.
C4.1: Identify/analyze the needs, stakes and constraints of several stakeholders
C9.4: Demonstrate rigour and critical thinking in approaching problems from all angles, scientific, environmental and human.

3CV2050 – Reliability of Structures and Risk Management

Instructors : **Christian Cremona, Pierre JEHEL**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **24,00**

Description

The development of efficient and relevant methods for the dimensioning and requalification of structures has become a major challenge today. The economic, societal and environmental stakes involved in the design, maintenance and operation of structures are a growing concern for public and private clients.
The need for relevant and efficient approaches that take into account uncertainties in loads, geometry, material properties, fabrication and installation, and operating conditions is widely felt.
Reliability theory, which is based on a probabilistic formulation of the performance of constructions, provides conceptually appropriate answers to these questions. Nevertheless, it raises theoretical, numerical and practical difficulties. However, it constitutes an original alternative for identifying the main factors of uncertainty occurring in structural systems or tests and controls that can increase their safety and efficiency.
This course has been designed to provide students with an overview of the methods at their disposal to implement a probabilistic approach to the performance of structures in their future activities. It presents the different concepts through examples that can be mostly done by hand; more complex real-world examples demonstrate their interest and operational implementation.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

The study of structural reliability involves calculating and predicting the probability of limit state violations at any age in the life of a structure. The probability of occurrence of such an event is a numerical measure of the likelihood of its occurrence. Once the probability is determined, the next objective is to select design alternatives for a structure to be constructed, or repair alternatives for a structure to be managed that improve structural reliability and minimize the risk of malfunction (failure).
Reliability analysis methods have found rapid application in multidisciplinary design due to stringent performance requirements, narrow safety margins, increasing liability, and increasing competition. In a design or requalification problem introducing uncertainties, a structure designed or evaluated using a deterministic approach may have a higher probability of failure than a structure of the same cost designed using a probabilistic approach that accounts for uncertainties. This is because the design requirements are precisely met in a deterministic approach and any variation in parameters could potentially violate system constraints.
The course is divided into 6 sessions as follows.
Session n°1 (3h): Performance, limit states, deterministic and probabilistic approaches and introduction to probabilistic methods
Session n°2 (6h): Reliability methods (components and systems), elasto-plastic analysis of failure shafts and mechano-probabilistic coupling
Session n°3 (3h): Tutorials - Exercises and case studies
Session n°4 (7h30): Tests, trials and controls and reliability of existing structures
Session n°5 (3h) : Tutorials - Exercises and case studies
Session n°6 (1h30) : Final exam

Class components (lecture, labs, etc.)

The course is based on a body of knowledge in probability theory and stochastic processes, finite element and boundary analysis that will need to be refreshed, consolidated or appropriated independently before and during the course. To this end, students will be provided with a course handout detailing principles and methods.
The course consists of 6 work sessions, carried out in a face-to-face session in a TD room. The tutorial sessions aim at verifying the assimilation of the methods on simple cases.

Grading

The assessment is based on the handing in of the tutorials within two days of the session and on a table-top assignment lasting between 1.5 and 2 hours,

Learning outcomes covered on the course

At the end of this education, the student will have acquired several levels of skills and will be able to :

Level 1: Knowledge of general principles

- Understand the notions of performance, risk, etc.
- Interpreting uncertainty in reliability theory
- Understanding the relative contributions of probabilistic and deterministic approache
- Assimilate the notions of components, systems, controls and fault trees

Level 2: Understanding of methods

- Calculate failure probabilities analytically on a simple case basis
- Assimilate numerical methods of reliability calculations
- Understand calculation approaches in complex cases
- Understanding the role of controls, tests and inspections in reliability control

Level 3: Applications

- Implement the course methods on simple cases
- To implement the course methods on numerical cases.
- Capturing the contribution of techniques on real-life examples

3CV2070 – Smart construction

Instructors : **Christian Cremona, Pierre JEHEL**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **15,00**

Description

The concept of "smart construction" or "intelligent construction" is often seen, if not defined, as the use by the construction sector of "digital" innovations. By adopting and exploiting these innovations, the goal is to be able to not only increase productivity, but also improve quality and safety.
While most industries have undergone tremendous changes over the past decades and have reaped the rewards of process and product innovations, the construction industry is just beginning to seize the technological opportunities that present itself. which places this sector in a stagnation of its productivity. However, the construction sector has vast potential for improvement thanks to “digital”, innovative construction methods, techniques and technologies. The rapid emergence of augmented reality, drones, digital and 3D printing, new construction materials… are part of this dynamic.
However, the concept of "smart construction" can also be defined as "enlightened construction", which does not only consist in a profusion of technologies, but also to apprehend construction in a more global way in its environment and its use. In this sense, ecodesign is also an enlightened vision of "smart construction".

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

The course offers a non-exhaustive overview of methods and techniques available today, in deployment or under development. The course is divided into 5 sessions as follows.
Session n ° 1 (3h): Introduction, ecodesign
Session n ° 2 (3h): New construction methods (Industrialization, prefabrication, automation, modular construction, 3D printing)
Session n ° 3 (3h): Parametric modeling
Session n ° 4 (3h): Giving a second life to structures: repair, rehabilitation, renovation
Session n ° 5 (3h): Sensors and instrumentation for construction + final exam

Grading

Assessment is based on :
- table-top MCQs lasting half an hour,
- a final test lasting one hour.

Learning outcomes covered on the course

At the end of this education, the student will have acquired several levels of skills and will be able to :

Level 1: Knowledge of general principles
- Appreciate the different concepts of smart construction
- Be aware of the evolution of the construction trades

Level 2: Understanding of methods
- Understand the current and future role of these techniques, methods and technologies for the construction sector
- Understand the concept of life cycle performance of construction
- Assess the impact of these methods and techniques on the professional sector in terms of productivity, performance, quality and safety.

Level 3: Applications
- Capturing the contribution of techniques on concrete examples

3CV2080 – City System

Instructors : **Frédérique Delmas-Jaubert**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **42,00**

Description

This course proposes a systemic approach to the city, hence the name Système Ville. The main objectives are :

- To understand the major urban issues at a time of ecological emergency and pandemic crisis.
- Seek ways to improve the performance and resilience of the city system
- Understanding issues of governance and circular economy in the digital revolution

The three days of classes will focus on discussions and work in sub-groups. The 4 days of project work will enable students to apply tools and knowledge to urban projects, in particular: i) the development balance sheet, ii) the carbon footprint, iii) mobility, iv) adapting to climate change, etc.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Course day 1: discover and understand

Knowledge inputs
- Issues of urbanization and major urban flows (GHG emissions globally and in the city - energy / transport / buildings / food / consumption)
- Notion of mitigating global warming at the urban scale / objective of carbon neutrality of urban areas
- Notion of adaptation to climate change
- Notion of inequalities and climate justice at the global scale and at the urban level
- Integration of the reports of GT2 and 3 of the IPCC, in the continuation of the GT1 report discussed in the "Earth System" course

Work in subgroups
- Realizations of Frescoes of the city
- Portraits of cities, e.g. Ile-de-France, India, USA, Africa (data / trends)

Course day 2: deepen and debate

Knowledge inputs
- The major players in the city system: public authorities, population, private players (designers, builders, flow operators, innovators, digital companies, etc.)
- Urban public policies related to climate and biodiversity, at national (e.g. climate-resilience law, national strategies), regional and then local (climate plans, instruments for regional/local strategies)
- Urban governance
- Sustainable city financing (adaptation / mitigation): in France and abroad
- 10 principles for a sustainable, peaceful and attractive city, with presentations of concrete projects and an urban walk to anchor these principles in reality

Work in subgroups
- Complement to city portraits (actors / public policies)

- Role play between stakeholders
- Contradictory debate
- Urban walk on the Saclay plateau

Class day 3: take action

Work in subgroups
- Work in pairs around concrete projects to take action for the benefit of the climate and biodiversity
- Restitution pitches in pairs

Project – session 1:
- Choice of study area
- Bibliographic diagnosis
- Establishment of working sub-groups: i) the development report, ii) the carbon footprint, iii) mobility, iv) adaptation to climate change

Project - sessions 2 and 3:
- Visit of the territory (in Ile de France)
- Deliverable: photo report + 1st documentary elements
- Sub-group work: library research, identification of courses of action, quantification

Project – sessions 4 and 5:
- Continuation of work in pairs
- Deliverable of the day: presentation of the issues to be shared with the large group

Project – sessions 6 and 7:
- Time to share the understanding of the challenges of each sub-group in the large group and review of the shared hypotheses
- In-depth study of each sub-group, consistency with the other sub-groups,

Project – session 8:
- defenses

Class components (lecture, labs, etc.)

Courses are partly recorded on video before the sessions (reverse class logic).
Lots of work and time for reflection in sub-groups.
During the last session, the students present orally a pitch on a theme of the CircularIDF project.

Grading

A continuous assessment will take place throughout the course. The final evaluation is done by the defense of the project at the end of the sequence

Resources

The teachers dream dream : Olivier Ledru and Fanny Guyot for the lessons, with Sébastien Corbon, Didier Lourdin and Frédérique Delmas for the project.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :
- Appreciate the notions of sustainable and intelligent city,
- Develop your own vision of the smart, sustainable city
- Applying and projecting this vision on a real territory

3CV2100 – Real estate, urban planning, urban development

Instructors : **Frédérique Delmas-Jaubert, Pierre JEHEL**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **21,00**

Description

- Real estate value chain: creation and capture of value from the investor to the operator
- The city's manufacturing tools: real estate operation, urban operation, planning, transport infrastructure
- Public and private actors involved in the process

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

1. Panorama of the value chain,
Identification of value chain players, exploration of their contractual and commercial relationships and regulatory milestones

2. Real estate editing: the process and valuation
The main stages of the real estate setup of an operation: land, diagnostics, economic feasibility, operational setup

3. Real estate operation and urban operation, Developer and Promoter, 2 models of manufacturing the city, with Armand Koestel, Grand Paris Aménagement
The planned city versus the city developed by opportunity, planners and promoters.
Public spaces and real estate operations.

4. In situ course on urban programming and the relationship between city and infrastructure (including industries), visit Paris Rive Gauche (F. Delmas + F. Cointe)
Built spaces, public spaces, architecture and infrastructure: learning to read the city, guided tour of the Paris Rive Gauche operation

5. Investing in real estate : state of the art and analysis of the impact of real estate

6. Investing in real estate: social and environmental responsibility (Thomas Rochefort)
Role and responsibility of the investor, multi-criteria assessment and financial reporting
Risk and return
Valuation of a real estate asset

7. Exam: role play: SIM URBA
In teams of 2 against a team of 2, you will negotiate lands to build (Greenfield or brownfield). Assessment of the relevance of the financial statements drawn up, the justification of the extra-financial criteria

Grading

The evaluation is made by the participation and the results of the role play Sim Urba, presenting an economic but also social and environmental assessment.

Resources

Dream team : Frédérique Delmas + Thomas Rochefort + Armand Koestel

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:

C1: complex systems

C1.1: Study a problem as a whole, the situation as a whole. Identify, formulate and analyze a problem in its scientific, economic and human dimensions

C1.3: Solve the problem with a practice of approximation, simulation and experimentation

C1.6: Mobilize a broad scientific and technical base within the framework of a transdisciplinary approach.

C4 sense of value creation

C4.1: Identify / analyze the needs, challenges and constraints of several stakeholders: residents, users, manufacturers, service providers, politicians, voters, ...

C4.2: Knowing how to identify the value provided by a solution for a client, the market. Know how to discern and seize opportunities, good business opportunities.

C6 be comfortable and innovative in the digital world

C6.6: Understanding the digital economy linked to the concept of smart city and the upheaval of the traditional economy of the city

C9.2: Perceive the scope of responsibility of the structures to which one contributes, by integrating the environmental, social and ethical dimensions

C9.4: Demonstrate rigor and critical thinking in approaching problems from all angles, scientific, human and economic

3CV2230 – From trees to wood, a renewable and efficiant material

Instructors : **Patrick Perre, Pierre JEHEL**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **24,00**

Description

Thanks to its unique combination of properties, wood and wood-based materials offer high-performance and innovative solutions for construction and even mobility (cars, rail networks). As a sustainable material capable of prolonging the CO2 storage provided by photosynthesis in trees, its use is growing rapidly and this trend is expected to strengthen further in the coming decades.

This general course on the material wood starts with a presentation of the role of wood in trees, a role that explains the properties of the material and its particularities. Then, wood as a construction material will be presented in detail: mechanical, thermal, and hydric behavior. The main families of materials currently available, their properties and how to obtain them will be presented at the end of the course.

Quarter number

SG11

Prerequisites (in terms of CS courses)

If possible, but not imperative: thermal transert and mechanical of continuous media

Syllabus

- Trees: plants with secondary growth (generating base that adds layers of cells year after year)
- Roles of wood in the tree :
    - the vascular system and the rise of raw sap...
    - mechanical support of the structure
    - adaptation of the structure to the environment
- Functional anatomy of wood
- Effect of plant stem functions on the properties of wood and their anisotropy
- Reminders on humid air and the resistance of materials
- The performance of wood materials = unique combination of properties, particularly thermal, water and mechanical properties
- From the wood in the tree to the material: cutting, drying, assembling, finishing
- Diversity and properties of wood-based materials
-

Class components (lecture, labs, etc.)

Lectures: 12h
Tutorial: 9h
Experimental labs: 3h

Grading

The submission of a written project (or mock-up) will serve as a check.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- Observe the trees with an insider's eye,
- To understand the behaviour of a hygroscopic material in relation to its environment,
- Properly dimension a strongly anisotropic beam,
- Quantifying water exchanges with a wall
- To gain a comprehensive understanding of the performance of wood and wood-based materials in construction.

3CV2250 – Risks Management and Forensic Engineering

Instructors : **Christian Cremona**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **21,00**

Description

Risk management is the antithesis of forensic engineering, and is an a priori approach. The former focuses on the analysis of accidents while the latter aims at preventing them. The basic steps of risk management are a) Identifying the hazard, b) Assessing the probability of its occurrence and the severity of its consequences, c) Combining their effect through a risk matrix to determine the risk of the hazard. The previous three steps constitute what is called "risk assessment". Depending on the magnitude of the risk, the adequacy of existing controls or the need for additional controls to reduce the adverse consequences of the risk within acceptable or at least tolerable limits should be considered.

According to this risk assessment, decisions can be taken, among which repair and rehabilitation play a major role.

Forensic engineering in construction can be defined as "the professional practice of determining the cause(s) of the failure of a structure, a work, a construction ... and to define the technical basis for identifying the parties responsible for this failure". The main objective of a forensic engineering expert is therefore to present in a factual manner all the information and data that can be collected after a failure in order to identify its cause, according to the available resources (time, personnel and financial means), which limits the scope of the investigation. The investigation therefore relies on all scientific and technological means, on testimonies and historical traces, to find an explanation for the failure.

Quarter number
SG11

Prerequisites (in terms of CS courses)
none

Syllabus

The course is divided into 7 sessions as follows.
Session n°1 (3h): Risk assessment and forensic engineering
Session n°2 (3h): Example of risk management based on experience feedback: independent span viaducts with prestressed beams (VIPP)
Session n°3 (3h): Place of inspection and controls in construction: principles and methods
Session n°4 (3h): Presentation of case studies
Session n°5 (3h): Assessment of existing structures
Session n°6 (3h): Methods and techniques of repair and rehabilitation
Session n°7 (3h): Presentation of case studies

Grading

The evaluation is based on :
table-top MCQs lasting a maximum of half an hour
a final test in the form of MCQs + exercise,
Case studies in small groups (3 students) leading to oral presentations of 30 minutes + written report (sessions 4 and 7).

Learning outcomes covered on the course

At the end of this education, the student will have acquired several levels of skills and will be able to :

Level 1: Knowledge of general principles
- Understand the concepts of risk assessment and forensic engineering
- Be vigilant at critical points in design and execution
- Evaluate the projects of structural repair

Level 2: Understanding of methods
- Implement a risk assessment
- Assimilate inspection and investigation methods
- Understanding the role of expertise in forensic engineering
- Understand the principles of assessment of existing structures and their repair

Level 3: Applications
- Analyze failure studies
- Implement risk management and forensic engineering principles
- Capturing the contribution of techniques on real-life examples

3CV2261 – Operational Excellence – Construction projects management

Instructors : **Pierre JEHEL**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **18,00**

Description

A construction project is a complex project that includes many stakeholders ranging from the client to the end users: the client formalizes a need and a program; the project managers – architects and technical design offices – translate the client need into specifications that comply with the state of the art, regulations and laws; the construction companies carrying out the work (execution methods, production scheduling, planning, coordination); the asset manager operates and maintains the construction. The scopes of action of each of these actors and the associated responsibilities are defined in the contracts concluded for the implementation of the project.

The performance of a project (costs, deadlines, quality, environmental impact, safety) is conditioned by good coordination between all the actors. Concepts and technological tools such as those of common data environment and Building Information Modeling appear in the normative and legal elements framing a construction project. Nevertheless a construction project is also a social process at the in which many actors collaborate. The performance of a project therefore also depends on operational excellence in its management.

This course aims at presenting the essential elements of operational excellence in a construction project:
- the main stakeholders in a construction project and their prerogatives;
- the different types of contracts and organizations implemented in public and private projects, in France and abroad;
- digital tools serving as a platform for exchange between actors.

The course also aims providing the students with a living experience of operational excellence in the specific context of a construction project and put them in a situation to practice project management methods.

Quarter number
SD9

Prerequisites (in terms of CS courses)
None

Syllabus

- The main actors in a construction project
- The main contracts and organizations set up in a construction project (public and private markets, public-private partnership, design-build-operate-maintenance)
- Lean construction (principles, methods, effects, what to remember, lean project management by practice)
- Leadership methods (leadership without hierarchical power - key success factor in projects)
- Target Value Delivery (by practice)
- Risk management
- BIM

Class components (lecture, labs, etc.)

The course sessions are concentrated over a week and are built according to different pedagogical methods according to their objectives: lecture, case study, serious game, individual or group work.

Grading

The evaluation is done on a Pass or Fail mode. The course is validated (Pass) if the following elements are gathered:

- Response to a questionnaire before the beginning of the course
- Critical note with knowledges and skills developed in the course
- No more than half a day of absence
- No absence during the half-days devoted to a serious game

Learning outcomes covered on the course

At the end of the course, students:

- know the different aspects of the performance of a construction project
- know the main actors of a construction project as well as their prerogatives for the success of the project
- know the principles of operational excellence in construction
- know how to apply methods oriented towards operational excellence in construction projects
- are able to understand the significant variance inherent in the different stages of a construction project
- have realized that a construction project is also a social process and will know how to use the appropriate digital tools accordingly

Description of the skills acquired at the end of the course

C3- Act, undertake and innovate in a scientific and technological environment
C4- Have a sense of creating value for one's company and clients
C5- Evolve and act in an international, intercultural and diverse environment
C8- Lead a project, a team
C9- Think and act as an ethical, responsible and honest engineer, taking into account environmental, social and societal dimensions

3CV2270 – Construction Processes for Buildings

Instructors : **Brice Bossan, Pierre JEHEL**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **15,00**

Description

The course aims at presenting the basic techniques of building construction.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

Session 1 (3h) - Buildings and equipments (description, characteristics, examples)

Course:

- Common buildings: residential and office buildings
- Others: hospitals, prisons, educational facilities, terminals, cultural spaces, stadiums, shopping centers, high-rise buildings / towers

Session 2 (3h) - Building formwork materials (description, operating principle, selection criteria)

Course:

- Standard formwork
- Special materials commonly used: column formwork, facade tools
- Exceptional special materials: self-climbing formwork for high-rise buildings, other examples (Stade de France, Tour First)

Session 3 (3h) - Construction methods, structural work planning, lifting equipments

Course:

- Choice of construction methods: structural analysis, selection criteria, comparison of solutions
- Structural work planning: determination of rates, procedure for establishing the schedule, choice of the number of cranes, validation by crane saturation, solutions to reduce crane times and / or the duration of the planning

Session 4 - Part 1 (1h) - Technical equipments (description, regulations)

Course:

- Heating - Ventilation - Air conditioning
- Plumbing
- Strong currents - weak currents

Session 4 - Part 2 (1h) - Architectural equipments (definition, regulations, examples)

Course:

- Insulation - Partitions - Lining
- Raised floors

- Interior joinery
- Floor coverings
- Dropped ceilings
- Metalwork

Session 5 (3h) - crane saturation

Course and hands-on:
- Definition, principle, exploitation of results
- Hands-on session

Grading

One-hour exam at the beginning of the 5th session of the course in the form of a series of questions.

Resources

Sessions 1 to 5: generic courses.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:

- Define the most suitable construction methods according to the characteristics of a building
- Propose realistic production rates, define the number of cranes required and establish the civil engineering work schedule
- Choose the appropriate materials for the construction of the structure
- Establish a coherent structural work cycle
- Know the main types of equipments

3CV2280 – Steel construction

Instructors : **Christian Cremona**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

The objectives of the course are:
1. To know about the properties and peculiarities of steel material for buildings and civil engineering structures, whether they are metal structures or mixed structures with other materials.
2. To understand the methods and tools for the design of metal structures from theoretical and regulatory aspects.
3. To know how to calculate the resistance and stability of steel structural elements according to the codes (Eurocodes).
4. To know about the different methods for assembling structural elements.
5. To understand the process of building a structure, and the execution standards that define the performances of structures.
6. To consider steel material from the viewpoints of circular economy and sustainable development.
7. To know about the current technologies and the technologies emerging for the production of steel structures (digital technologies, robotics).

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Session 1 (3 hours of lessons)
Steel and its use in construction, its properties. Regulations and standards.
Brief history of iron and steel. Use of steel in the world - Key figures. The metal construction market; businesses. Methods of production and processing. Basic steel products. Steel and sustainable development. The circular economy from recycling to re-employment. Extended Producers Responsibility. Generic properties of structural steels. Ductility, elastoplasticity, resilience & tenacity (DEPRT). General bases of the design and realization of in steel construction - standards and regulations. Organization of Eurocodes - Reminders on reliability - Partial safety factors. Reminders on the concepts of load assumptions and combination of actions.

Session 2 (3 hours of lessons)
The plastic resistance of steel elements; Forms of instabilities (1).
Notations & Units in Metal Construction. Designation and choice of steels - Nominal characters. Elasticity / Plasticity - Reminders of structural mechanics. Shear of steel sections. The tensile strength of steel sections. Plastic interaction - principles and formulation. Plastic hinges / Redistribution of plasticity forces. The forms of instabilities of a steel bar. The four section classes. Eurocode strategy in class 4. Verification of cross sections according to Eurocode 3. Buckling (universal curve and resistance to buckling). Torsional buckling of beams.

Session 3 (3 hours of lessons)
Instabilities (2) and structural analysis (design principles).
General principles of design. Stabilization of structures. Typology of load-bearing elements. Stabilization by bars. Stabilization by diaphragm effect. Bending. Structural analysis in Steel Construction, notions of initial imperfections and second order effects. Bracing systems and assemblies. Global structural imperfections: regulatory approach, consequences on the modeling of structures and calculation of bars. Concept of flexible and rigid structure, with fixed or movable nodes. Definition and choice of structural analysis methods and associated verifications. Methods for determining buckling lengths or critical loads. Bar stability checks.
Session 4 (2 hours of lessons + 1 hour of tutorials)

The ELS - The assemblies in Metal Construction - The mixed structures.
The SLS (Serviceability Limit State) in deformation and user comfort. Mixed steel-concrete structures. Multi-material structures: steel, wood, glass, textile membranes. Assemblies in metal constructions. Component method according to Eurocode 3. Weldability and welding in metal construction.

Session 5 (3 hours of lessons)
Steel in accident situations - Steel and dynamic actions - Stainless steel - The execution standard for metal structures.
Steel structures and the action of the wind. Steel structures and dynamic actions - Notions of fatigue. Steel in an accidental situation: Earthquake, Fire. Stainless steel under construction. Execution standard EN 1090-2 & European Construction Products Regulation. Example of application of the methods: the Canopy and tolerance control. Panorama on digital technologies and manufacturing tools - smart factory.

Grading

The evaluation will be done continuously based on an individual building project which will serve throughout the course, from the genesis of load assumptions to the calculation of certain bars, and a critical analysis of the design choices.
This project will be presented and the expectations will be explained during the second class session. Personal work after sessions 2, 3, and 4 will be necessary. The expected results could be to carry out a bibliographical research on a particular topic.
The complete project will be finalized and delivered during the last session (session 5). Half an hour will be left at the end of the course so that the students can review, amend, and complete their file.
During the fourth session, 1 hour will be reserved for a correction of practical exercises, which will have been posted online after session 3.
The aim of the project will be to cover different stages of the design of a structure, such as for example: developing the hypotheses / defining the actions / choosing the modes of stability / choosing the method for calculating the stresses / choosing the materials and the sections to be used / designing certain components / possibly comparing different technical options.
The projects are to be carried out individually (1 project per student).

Learning outcomes covered on the course

At the end of this course, the student will be able to:

- Understand how steel structures are working and how to design them.
- Know and understand the properties and performances required for the choice of a steel along with the standardized terminology.
- Know how to calculate steel elements (bars) in terms of both resistance and stability.
- Know how to calculate or understand the elastoplastic interaction of a steel section.
- Understand the notion of structural analysis and the different modeling methods in steel construction.
- Know the different techniques for assembling structures.
- Know the parts of the codes useful for understanding the design of a structure.
- Know the expectations of the execution standards.
- Learn about sustainable development, circular economy, the world of steel and how metal construction companies approach their construction market.

3CV2300 – Mobility and Transportation Infrastructures

Instructors : **Frédérique Delmas-Jaubert**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **24,00**

Description

This course aims at posing the challenges of mobility on a regional, national and international scale starting with an understanding of transport infrastructures.
The aim of the course is to enable students to think of transport as one of the elements of the organization of the city, the metropolis, or that of interurban connections. It is based on the history of the networks that now shape the organization and structuring of our territories with the common interest and the common good as a common thread. It is a course that questions the why of infrastructure choices in order to provide political decision-makers with technical contributors who see far, well beyond the prevailing short-termism. Finally, the course is resolutely committed to disruptive approaches to support the fight against climate change.
The course allows the interrogation, the questioning of the infrastructures and facilitates the reasoning to maximize the existing infrastructure networks, their reversibility or that of new uses to save land, avoid new urban cuts and create social ties. More than ever, the new paradigms that have appeared since the corona virus crisis require a new reading of decision or profitability indicators and of optimizing the transport assets in a context where societal expectations have become prevalent.
In this context, the road network is the subject of 3 specific sessions, which will provide a better understanding of its history, road techniques and the challenges of the road of the future.

Quarter number
SG11

Prerequisites (in terms of CS courses)
none

Syllabus

Session 1.
Passenger transport, freight transport
Public transport, individual trips
Infrastructures and vehicles, towards mobility as a service (Maas)
Public services, private services
History and perspective

Session 2.
Some recent major projects, case studies, for example (not the final list):
- The Grand Paris Express (regional scale)
- New Paris Normandy line (national scale)
- Lyon -Turin (international scale)
Tutorials: prioritization of the various infrastructures in a chosen territory

Session 3.
Which indicators to measure the performance of transport systems?
Socio-economic studies
The environmental impact
The carbon footprint
Tutorials: multi-criteria comparison of connections near the campus (to the Guichet station for example)

Session 4.
The road network: historical approach
Integration into multimodal journeys
The game of actors: decision-makers, funders, designers, directors
The key numbers
The jobs of today and tomorrow

Session 5.
Road techniques: roads, highways, tarmac, cycle paths
Innovations, technological breakthroughs, ecological transition and decarbonization of road manufacturing
Link with bridges and tunnels?
Tutorials: Practical case / dimensioning?

Session 6.
Multimodal traffic forecast models and their source data
- Global household surveys
- Telephone / internet data for transport models
Technological innovations to limit the carbon footprint and optimize performance
Tutorials: response to a call for innovative projects (such as that of Grenoble, or another)

Session 7.
The road of the future, in town and in interurban
infrastructure related to electric vehicles, vehicle developments and infrastructure developments
The road as an energy producer?
What new services provided by the infrastructure?

Session 8.
Debate: is the autonomous vehicle the future of the city? on land and in the air
Tutorials: continuation of the response to the call for innovative projects

Grading

The evaluation is done with oral presentation of thematic research in little groups

Resources

The teaching team consists of Didier Lourdin and another instructor for the road section.

Learning outcomes covered on the course

The course allows students to:

- identify the links between mobility and the construction of infrastructure, mobility and land use planning, and more broadly mobility and city construction,
- study the impacts of mobility on the territories and the opportunities offered,
- understand the interplay of economic and political actors,
- understand and manipulate the social, economic, and environmental performance indicators of transport modes, carry out comparisons between the different modes,
- learn how to design a road and what are the traditional materials for infrastructure,
- identify and work on technological obstacles to innovation, as well as operational obstacles (decision makers, local blockages, necessary investments, etc.),
- understand the transformations at work in mobility in the context of the ecological and health crisis.

3CV2310 – Dams, bridges, marine and underground engineering

Instructors : **Pierre JEHEL, Brice Bossan**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **15,00**

Description

The objectives of the course are to introduce the vocabulary, the technology and methodologies used on Civil Engineering worksites.

Quarter number

SD9

Prerequisites (in terms of CS courses)

none

Syllabus

- Session 1 (3h) : Geotechnical specificities / Earthwork
- Session 2 (3h): Underground civil engineering structures (caverns, metro stations...)
- Session 3 (3h): Underground work (tunnel boring machine and traditional work)
- Session 4 (3h): Port facilities.
- Session 5 (3h): Dams

Class components (lecture, labs, etc.)

Each of the 3-hour sessions includes 1.5 hours of class followed by 1.5 hours of tutorials in project mode.

Grading

A 90-minute exam in class. The questions correspond to points raised either in in the course or in the application project.

Learning outcomes covered on the course

At the end of this course, the student will be able to:

- Work in groups
- Understand the relationship between design - construciton methods - construction
- Present the progress of a project and summarize the impact of the choices made

3CV2320 – Geotechnical Engineering

Instructors : **Christian Cremona**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

The objectives of the course are to know the general principles and methods of reasoning used in geotechnics, as well as to introduce its application to the design of elementary structures.
The course is not intended to train specialists, but to provide the basic knowledge indispensable to any Engineer called upon to play a role in the orientation or general design of a Building or Civil Engineering project, and to enable him/her to establish a constructive dialogue with the Geotechnician at the various stages of the construction of the structure.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Session 1 (3h) - Course: The soil, heterogeneous medium and the soil, discontinuous medium
Session 2 (3h) - Lecture and TD: Soil, continuous medium & water in the soil
Session 3 (3h) - Lecture and TD: Ground Deformations
Session 4 (3h) - Lecture and TD: Soil Resistance
Session 5 (3h) - Lecture and TD: Applications

Grading

Continuous assessment requiring intermediate work after each session (2, 3, 4 and 5), to be carried out individually by the student.
With a geotechnical project serving as a baseline - a large-scale container dock - the work will focus on various geotechnical issues, including:
- Characterization of embankments
- Estimation of water arrivals in an excavation
- Long-term settlement of compressible layers
- Shear strength parameters
- Behavior of geotechnical structures

The work will include parametric / computational analyzes as well as bibliographic research on the topics presented. Students will return their work before the next session (for sessions 2, 3 and 4) or 1 week after the last session (for session 5).

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :
- Identify the main types of soils
- Understand the issues associated with the behaviour of the main soil types
- Applying this knowledge to the design of elementary structures

3CV2350 – Acoustics

Instructors : **Pierre JEHEL, Pierre-Étienne Gautier**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **15,00**

Description

The need to take into account environmental constraints, in particular acoustic in construction projects (in terms of exposure to noise) or infrastructure (emitted noise), as well as the need to guarantee the interior acoustic quality of buildings or transport vehicles, make it essential to acquire a basic culture in acoustics for engineers managing construction or infrastructure projects. This course aims at providing the bases in acoustics that are necessary to address these questions, based on concrete examples (railway infrastructure, concert hall, etc.).

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Basic concepts and equations, measurement, environmental noise indicators, legislative context, basic solutions: plane, cylindrical, spherical waves.
Basic acoustic sources: monopoles, dipoles, acoustic radiation of structures, acoustics of closed spaces (eigen-modes) or semi open (waveguides).
Room acoustics.
Propagation / influence of weather / acoustic screens.
Example of railway noise: Sources: rolling noise, aerodynamic noise, reduction.

Grading

Project in teams of 2 students developed in parallel with the course and evaluated by a defense.

Learning outcomes covered on the course

Basic knowledge of the main concepts in acoustics (equations, models of sources and radiation, measurement and indicators, bases of propagation and diffraction by screens, diffuse-field models for rooms).
Knowledge of basic acoustic indicators used in regulations.
Ability to model noise sources (railway case) or the acoustic atmosphere of a space (room, hall, vehicle interior).
Ability to establish simple models of infrastructure emissions, industrial noise, building exposure or interior ambience of a cabin or concert hall.

3CV2360 – Project in Construction Engineering

Instructors : **Pierre JEHEL, Brice Bossan**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **24,00**

Description

This course takes the form of a General Construction Engineering project to be carried out in one of the 3 main themes covered in the prerequisite courses:

- 3CV2310 Civil engineering (buried works, underground works, port development, dams)
- 3CV2020 Bridge
- 3CV2270 Building

The choice of the type of project is left to the students according to their prerequisites.

Civil Engineering project:

Students are placed in a situation of developing a project on one of the following themes of their choice:

- Buried structures (storage basin, cave, metro station, etc.)
- Underground structures (tunnels, branches, niches, galleries, etc.)
- Port development (dike, quays, etc.)
- Dams (earth, concrete, etc.)

Each group must:

- Explain the choice of design, particularly regarding the economic and environmental context, in a technical brief
- Establish a methodological notice for the project
- Write a pre-design note

Bridge Engineering project:

This is a team project where each team is expected to design a bridge starting from the description of a gap. The students are expected to:

- Choose the type of structure to build
- Design the main characteristics of the structure (distribution of spans, dimensions of the cross sections, prestressing, etc.)
- Model (in a simplified but sufficiently complex way) using the RDM7 software(*)
- Define the actions and use the model to calculate the internal forces and their combinations according to standards
- Design the sections.
- Present the calculations in the form of a calculation note

In addition, the teams are asked to make drawings of their work (elevations, longitudinal sections, cross sections as well as some details) and to define and present the general construction method.
During the first 4 sessions of the project, one hour is dedicated to providing additional theoretical elements necessary for the modeling and design of structures:

- Using the RDM7 software(*) and other tools
- How to model a structure
- Actions to be applied on the bridges (simplified) and combinations to be adopted
- Designing of a section.
- Producing a calculation note.

(*) RDM7 is a free and basic software for static analysis. Its interface is very basic as is the representation of the output data. As a result, it is very pedagogic because it requires the future engineer to understand and master the modeling of its structure and the actions applied from start to end.

Building Engineering project:

- The first 4 project sessions are devoted to courses aimed at properly introducing the elements necessary for the realization of the projects. These sessions are specific to the topics covered in the projects and complement the generic sessions of the course 3CV2270.
- Based on real building projects, students are expected to define the appropriate construction solutions.
- Expectations: choice of construction methods, achievable execution rates, means to be implemented to meet the client's deadline and establishment of the schedule. Secondly, two "execution" type studies dealing with the cycle and shoring are to be dealt with.

Quarter number

SG11

Prerequisites (in terms of CS courses)

- 3CV2310 to be eligible to a civil engineering project
- 3CV2020 to be eligible to a bridge project
- 3CV2270 to be eligible to a building project

Class components (lecture, labs, etc.)

Teams of 2 to 4 students working in project mode.

Grading

The last session is devoted to a defense during which each team of students presents their project in front of a jury.

The individual evaluation of the students is based on this defense. The grading takes the following into account:

- Quality of the presentation and associated documents
- Quality and consistency of the project developed
- Argumentation of technical choices
- Ability to make a synthetic presentation of the results.

An overall score is assigned to each project based on these criteria. The individual grades of the students in a same team can be modified by 1 or 2 points around this overall mark according to the contributions of the different members of a team.

Description of the skills acquired at the end of the course

- Analyzing and designing complex systems (C1)
- Being convincing (C7)
- Leading a team project (C8)
- Thinking and acting as an ethical, responsible engineer (C9)

3CV2500 – SIC Project

Instructors : **Pierre JEHEL**
Department : **MENTION SCIENCES & INGÉNIERIES DE LA CONSTRUCTION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

A *Project Jean Muller* places a team of students in front of an open engineering problem with a research component. It is commissioned by an industrial, institutional, or associative partner that is referred to as the *client*. The client is active in the construction sector (buildings, infrastructures, cities).

A project team consists in three or four students, a representative of the client and, where applicable, a professor or researcher from CentraleSupélec who adds his or her skills and expertise to those of the students. Within the project team, the students work begins with the understanding of the problem and the expression of the client's need. Then, the students organize the implementation of a scientific approach leading to results that are validated by the client and that can be presented to a non-expert scientific audience.

As the project corresponds to a real and open issues, strong added value is expected from the students work.

Project management is mainly left to the students to develop their autonomy and adopt an engineering approach.

Quarter number
SG10 SG11

Prerequisites (in terms of CS courses)
none

Syllabus

Project work slots are scheduled regularly throughout the year. The organization of work during these sessions is left to the management of the project teams. The life of the project is cadenced by three milestones corresponding to different phases of the project: start, mid-term, end. The start-up phase may include visits to present the project in its context.

Class components (lecture, labs, etc.)

The project teams are made up of 3 or 4 students, 1 (or more) representative of the client and, where applicable, a professor or researcher from CentraleSupélec.
Each team is monitored by an advisor who ensures the effective conduct of the project through regular meetings with the project team. The pedagogical advisor is not involved in the technical realization of the project.
Three milestones are common to all projects:
1. October: assessment of the start-up period. A few slides are expected with a description of the understanding of the topic, tasks completed or in progress, planning.
2. January: report and intermediate deliverables addressed to the client and defended in front of a jury.
3. April: report and final deliverables sent to the client, final defense.

Grading

The 2 defenses in January and April are evaluated according to the following methods:

- Grade N1 - Project management and results (understanding of the client's need and of the context, project management (organization of the work, autonomy, maturity), creation of value / results / performance -> evaluated by the jury

- Grade N2 - Defense -> evaluated by the jury
- Grade N3 - Report -> evaluated by the client
-

Grade then assessed from the rounding of the formula 0.5 x N1 + 0.25 x N2 + 0.25 x N3.

Learning outcomes covered on the course

At the end of this course, the students will have demonstrated:

- Their ability to work on an open topic requiring a scientific and pragmatic approach.
- Their ability to collect and analyze research results in order to implement them and, as far as possible, develop them within the framework of the project.
- A certain maturity in the conduct of projects: autonomy in management, organization of work, regular meetings with the client to understand his or her needs and meet his or her expectations.
- Their ability to deliver results with an appropriate judgement on their value, performance, limitations.
- Their ability to provide high-quality and clear deliverables on time.
- Their ability to convincingly convey in writing and orally a scientific approach, technical results and well-argued recommendations.

3CV3010 – Embedded Energy Systems

Instructors : **Loïc Queval**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

This course aims to give a vision of the different configurations that respond to the problems of energy production and distribution in an embedded system. It mainly deals with the specific problems of electrical energy management in embedded systems in order to control the dimensioning of these systems. It is divided into three parts: the first deals with the principle and models for embedded energy devices, the second deals specifically with rolling electrical systems, and the second with aircraft networks. The presentations are accompanied by case studies.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Electrical energy fundamentals : Electrical Energy lecture for example

Syllabus

P*rinciples and models for embedded energy*
Challenges of on-board energy. Constraints of the main on-board systems. Parameters and models of electrical systems. Review of the solutions available for power generation. Conversion systems. Impact of regeneration. Problem of the dimensioning of the components of the conversion chain. Typical applications of on-board energy.

Aircraft networks
Definition and characteristics of the various components of an aircraft system. Integration of the electrical system in the aircraft. Validation and verification process. Changes in the sector towards the plus and all electric. Description of the needs and contribution of electrical equipment. The choice of voltage (AC or DC, which level?), the constraints and operating conditions of an on-board system: stability of the DC bus (impact of the presence of a battery). Reliability of embedded systems: definition, operating strategies in degraded mode (redundancy, ...). Some elements are given on the pneumatic and hydraulic networks used in aircraft.

Energy storage
Definitions and operating principles. Constraints and evolution of applications. Lead-Acid batteries for micro-hybrid system. Nickel Metal Hydride (NiMH) batteries for full hybrid systems. Lithium-Ion batteries for electric or hybrid vehicles. Characteristics of components, design elements, dynamic characteristics. Outlook.

Railway drives and Hybridization
Architecture and components of a traction system. Constraints for electric traction. Main modes of energy supply. Organization of the energy transfer chain for traction. Different architectures for hybridization. Different means for energy storage. Fuel cell. Hydrogen sector. Storage of hydrogen. Applications.

Innovations for energy embedded systems
Overview of new means of transportation: maglev, hyperloop, all-electric aircraft, etc. Associated technological development: magnetic bearings, superconducting machines, etc. Constraints on the corresponding on-board energy systems and new architectures to address them.

Class components (lecture, labs, etc.)

Lectures

Grading

The evaluation will be done by a file carried out as a group and which will have to deal with one of the "use cases" proposed by the various lecturers.

Resources

Three hours lectures given by the members of the team.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- Know the electrical power system that powers an airplane
- Offering power supply devices for vehicles
- Formulate an opinion on electrical solutions in an on-board system
- Distinguish the advantages and disadvantages of each source of electrical energy
- Choose a suitable electric traction/propulsion device

Description of the skills acquired at the end of the course

C2.1;C2.2;C2.3

3CV3020 – Aerodynamics

Instructors : **Antoine Renaud**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **37**
On-site hours (HPE) : **23,00**

Description

The purpose of the aerodynamics course is to present to students the effects caused by the introduction of an obstacle into a flow and the resulting forces. These effects are, of course, used in aeronautics but also concern other fields such as land and sea transport or even construction.
The goal is to be able to determine the forces exerted on a thin object whose geometry is known and to calculate them with different levels of approximation.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Flight mechanics
Applied fluid mechanics

Syllabus

Session 1: Fundamentals

Airplane geometry, vocabulary, link between lift and circulation
Session 2: Infinite span profile

Equations, distribution of vortices, Glauert's integrals
Session 3: Finite span wing

Wake, circulation distribution, induced velocity, induced drag
Session 4: Boundary layer: introduction

Limits of non-viscous models, boundary layer concept
Session 5: Laminar boundary layer: exact solutions

Blasius and Falkner-Skan solutions
Session 6: Laminar boundary layer: approximate solutions and transition

Karman-Polhausen method, boundary layer detachment, transition to turbulence
Session 7: Turbulent boundary layer

Properties, averaged model, sub-layers description

Class components (lecture, labs, etc.)

The course follows an "inverted class" framework and the content is provided using videos and a book.
There are seven sessions. The students must watch and understand the corresponding videos beforehand. The sessions are dedicated to exercises and a project.
Session 1: introductory lecture (1h30) + exercises (1h30)
Sessions 2 to 7: exercises (1h30) + project (1h30)

Grading

2 hour long exam (calculator and limited notes (1 A4 sheet front and back) allowed) + short report on the project

Resources

This course follows an "inverted class" framework. During sessions, the students will be practicing exercises and working on a project.

Learning outcomes covered on the course

At the end of the course, the student will be able to:

- Identify the physical phenomena responsible for lift and drag
- Understand the link between the geometry and the performance of a wing
- Calculate the lift and the induced drag of a thin wing with a given profile
- Know the different types and behaviors of boundary layers
- Calculate the friction drag for a given wing

Description of the skills acquired at the end of the course

C1.2: Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem

C1.3: Solve problems using approximation, simulation and experimentation

C2.1: Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.

C3.6: Evaluate the efficiency, feasibility and strength of the proposed solutions

3CV3030 – Structural dynamics

Instructors : **Andrea Barbarulo**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **20,00**

Description

In the field of dynamic phenomena, periodic vibrations in a bounded environment are of paramount importance, since vibrations occurring in a structure can seriously compromise its mechanical strength. These phenomena are also encountered in the generation and propagation of noise.

In this course, the basics of vibration dynamics will be presented with a particular focus on its importance in the context of transport, aeronautics and space.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

Course outline (content)
- Single-degree-of-freedom systems and introduction of basic tools
- Reminders of continuous media mechanics and analytical solutions
- Principle of virtual powers and introduction to modal analysis
- Rotating reference frames
- Introduction to finite elements in dynamics

Grading

100% written 2h

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- Understand vibrational behavior and its importance

- Analyzing the modal behavior of a structure

- Dimensioning a system according to the basic principles of vibration mechanics

3CV3040 – Flight mechanics

Instructors : **Olivier Gicquel**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **33**
On-site hours (HPE) : **20,00**

Description

This course presents the basics of understanding how the performance of an aircraft and its dynamic behavior are determined. It is structured into seven three-hour course sequences and a one-and-a-half hour control sequence. Each sequence of courses includes two hours of knowledge and one hour of practice.

Quarter number

SD9

Prerequisites (in terms of CS courses)

none

Syllabus

- Sequence 1: Introduction of basic quantities: notion of speed, altitude and aerodynamics. Introduction of the equations governing the motion of the aircraft. Case of gliding.
- Sequence 2: Analysis of uniform horizontal flight and climbing flight.
- Sequence 3: Descent flight, Determination and calculation of load factors.
- Sequence 4: Calculation of the range and endurance of an aircraft. Method for determining take-off and landing distances.
- Sequence 5: Study of the longitudinal and transverse static equilibrium of an aircraft. Introduction of the notion of static margin.
- Sequence 6: Study of the dynamics of the aircraft and its eigenmodes.
- Sequence 7: Implementation of eigenmodes calculation under Matlab or Python (students can choose). Put into practice by the construction and optimization of a polystyrene plane.
- Sequence 8 : Control 1h30

Grading

The test takes the form of a written test on an open topic which the students should be able to deal with on their own on the basis of the knowledge acquired during the course.

Description of the skills acquired at the end of the course

At the end of this course, students will be able to characterize whether their aircraft is capable of meeting the main characteristics of a specification: Flight speed, Minimum operating radius, Maximum climb slope, Take-off distance, Static margin, Damping rate of the aircraft's eigenmodes... They will also be able to identify which magnitudes they can play on to improve the performance of their aircraft.

3CV3050 – Turbulence and boundary layers

Instructors : **Ronan Vicquelin**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Turbulent flows are found in most industrial applications. In internal or jet-type flows, turbulence favours different types of transfers: quantity of movement, energy, species. The same is true for external flows around profiles where a turbulent boundary layer develops. These properties can be appreciated (improved mixing for example) or penalized (increased drag and pressure drops). The understanding and modelling of turbulence is, moreover, recognised as one of the most difficult problems in classical physics.

The course addresses several characteristics of turbulent flows: fundamental mechanisms, Kolmogorov cascade, balance equations, case of flows in simple configuration. The different approaches (RANS, LES, DNS) related to the necessary description and modelling of turbulence are also presented and contextualised in the context of industrial and academic applications.

The evaluated project consists of several parts started during the course sessions. This project allows students to become familiar with the implementation of a RANS calculation with Ansys Fluent software, to study canonical configurations in order to find the classical properties of some particular turbulent flows (boundary layer, jet). The last part of the project is the opportunity to carry out a critical analysis of a complex flow.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

Session 1: Fundamental mechanisms, Kolmogorov cascade
Lecture: Introduction & Generalities; Production, Dissipation, Transfer between scales; Energy and dissipative scales; Kolmogorov cascade
TD: DNS cost, THI decay

Session 2: Averaged balance equations
Lecture: Direct numerical simulation (DNS); Reynolds decomposition; Averaged balance equations (RANS); Closure problem, Reynolds tensor; Turbulent transfer flows (heat, species)
TD: Starting the project

Session 3: TD Two-dimensional turbulent jet

Session 4: RANS closure models
Lecture: Reynolds tensor properties; Boussinesq hypothesis, Turbulent diffusion; Turbulent and total/effective viscosity; Gradient diffusion hypothesis; Turbulent Prandtl and Schmidt numbers; Algebraic, one-equation, two-equation models; Standard k-ε model.
TD: Continuation of the Project

Session 5: Parietal turbulent flows

Lesson: Channel flows (steady state, etc.); Mechanical and thermal boundary layer structure; Total stress and flow; Friction velocity and temperature; External/internal zone; Viscous sublayer/Tampon zone/Logarithmic zone; Implicit cf(Re) friction law.

Session 6: Project

Session 7: Project

Session 8: Spectral analysis and large-scale simulation

Lecture: Turbulent kinetic energy spectrum, dissipation, production; Inertial zone of the spectrum; Transfer between scales; Large-scale simulation (LES); Filter definitions; Filtered equations, subgrid models; Smagorinsky model; LES advantages/disadvantages, wall models and hybrid approaches.

TD: Project support

Class components (lecture, labs, etc.)

It is recommended that you have taken the CFD course, which includes training in the use of Ansys Fluent. However, prior training in Fluent is not compulsory insofar as its use in the project is presented during the course. 8 class sessions + 20 min. presentation during a time slot a few weeks after the last session.

Grading

The mark is composed of two elements:

- An N1 grade linked to a report o, the first part of the project. The questions are detailed to guide students and illustrate the concepts of the course.
- A grade N2 linked to a defense on the final part of the project. The subject is here open and allows to evaluate the analysis capacities.

The work for N1 and N2 is carried out by a pair of students. The final grade is obtained by weighting the marks N1 and N2 at 50%.

Learning outcomes covered on the course

- At the end of this teaching, the student will be able to :
- Make a rough dimensioning of the key quantities of a turbulent flow...
- Judging the advantages/disadvantages of a turbulence modelling approach
- Recognize the fundamental properties of a simple turbulent flow: jet, boundary layer without pressure gradient
- Conducting and analyzing numerical simulations of turbulent flows

3CV3060 – Automatic Control Applied to Aircraft

Instructors : **Antoine Renaud**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The purpose of this study is to discover techniques for the design of a digital (or discrete-time) controller through an application consisting in elaborating the digital control loop for the stabilization of an aircraft (control laws). The focus here will be on the stabilization of the aircraft's incidence oscillation mode (rapid longitudinal movement around its centre of gravity) and the control of the angle of incidence so as to give the aircraft good flight qualities. The progressive progression of the study, in connection with the courses of automatic and flight mechanics, will lead to approach first of all the preliminary treatment of the signals measured on board the aircraft to guarantee the quality of their necessary digitization, then various discretized control laws of the aircraft will be developed, tested and analyzed, and finally these laws will be increased by a discretized observer making it possible to free oneself from certain measurements.

The aim of this course is to raise awareness of the main problems encountered by automation engineers in charge of system control.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

1: Detailed study of a Digital Low Pass Filter

- equation setting
- temporal analysis (simulation), frequency analysis (Bode, Nichols)
- discretization (Euler, Tustin, transformed into z, blocker of any order)
- detailed study of the effect of blocking (anti-aliasing filtering)
- generalization of these methods to a continuous linear system of any order

2 : Realization of digital compensators by state feedback

- equating the longitudinal motion of an aircraft around its centre of gravity at a given point of flight and developing the associated continuous linear model
- modal analysis and system stability
- design of a control law in the continuous domain: pole placement and optimal control by complete static feedback, dynamic advance-delay compensator (output feedback)
- closed-loop testing (simulation) and margin studies (Nichols)
- digitization of controllers and closed-loop testing
- study of the effect of a vertical wind, and the influence of the static margin of the aircraft

3: Digital control by output feedback and observer

- study and development of an observer (Luenberger)
- modal analysis and closed-loop testing (simulation

- elements of robustness and performance (integral action)

Class components (lecture, labs, etc.)

The course is delivered in a standard room equipped with video projection facilities.

The activity includes 8 face-to-face sessions of 3 hours (+ a 15-minute break). Sessions 1 to 3 deal with point 1 of the course outline, sessions 4 to 6 deal with point 2 and sessions 7 and 8 are devoted to point 3. Each session begins briefly with an interactive presentation of several aspects of the job of an aircraft control law design engineer, followed by a declination of the fundamental academic notions of automatic control in the industrial environment. Most of the time is then devoted to direct implementation exercises on the aeronautical application described above, with the continuous assistance of the teachers. The detailed description of the topics to be covered and their sequential sequence are the subject of a document that will be given to each student at the first session, as well as a course material. An attendance sheet must be signed at each session.

Students are divided into pairs. Each pair must be equipped with a personal PC with the Matlab/Simulink software package.

Grading

The evaluation of the acquisition of knowledge is carried out on the basis of "engineer's report" type documents written by each pair and given to the teachers. Student participation and motivation are taken into account in the evaluation of the activity of the pairs.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- develop and analyse an elementary control loop on a linear dynamic system
- specify the characteristics of the subsystems supporting the control function (actuators, sensors, computer) in relation to the intended system performance
- master temporal simulations of any dynamic system with Simulink, and use Matlab's control capabilities
- to understand the essential notions of Industrial Automation

3CV3070 – Advanced Structural dynamics

Instructors : **Andrea Barbarulo**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Once the basics of structural dynamics are acquired, advanced theoretical and numerical tools are needed to understand more complex phenomena. In particular, modal finite element analysis has limitations when the frequency of analysis is increased. These phenomena at medium and high frequencies are of paramount importance in noise propagation and fatigue behaviour of structures.

The objective of this course is to understand these phenomena and to introduce the associated theoretical and numerical tools.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Stuctural dynamics

Grading

1h d'écrit et un rapport de B.E.

Learning outcomes covered on the course

Upon completion of this course, students will be able to:
- Understand medium and high frequency behavior and the importance of introducing alternative methods
- Develop a critical vision of the different possibilities of modeling a vibrating system
- Know how to manipulate numerical methods

3CV3080 – Performance pre-design case study

Instructors : **Antoine Renaud**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **30,00**

Description

This teaching brings, through practice, an awareness of the design of complex systems for which some initial choices have repercussions on the whole system.

The case implemented by the students concerns the development of an industrial method for the pre-dimensioning and preliminary design of an electric aircraft (Dassault Aviation), an electric car (Renault) or the energy system of a satellite (Thales Alenia Space).

The work consists of dimensioning the system with the aim of achieving the performance specified in a specification. This pre-dimensioning must lead to choices of architecture and compromises through iterations.

Practical cases are supervised by engineers from Dassault Aviation, Renault or Thales Alenia Space.

In particular, the case studies address the issue of new energies or new technologies in transport (electrification, autonomy, etc.).

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

The teaching is a case study dimensioned specifically for engineering students in their final year of study. It is given over a blocked week and alternates theoretical contributions concerning technologies that the students must quickly appropriate during the lectures and practical work. The work carried out in pairs follows a common thread and an intense rhythm, leading to the definition of a complete system validated by performance simulations.

Class components (lecture, labs, etc.)

The work is done in small groups, with computers in a TD room. The necessary software is either generic (Excel, Matlab...) or provided by industrial stakeholders. The course lasts a full week.

Grading

Presentations carried out by each group of students during the week .

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- Implement notions specific to the different fields and analyse their interactions.
  Dassault aviation: applied aerodynamics / aircraft performance / aeronautical structures / layout
  Renault : electric propulsion / battery sizing / cost-performance trade-off
  Thales Alenia Space: meeting mission objectives / energy management

- Use business tools for pre-sizing and performance characterization
  Dassault aviation: electric aircraft pre-sizing software and digital wind tunnel software
  Renault: engine sizing, batteries and standard homologation cycles
  Thales Alenia Space: orbit computation

3CV3210 – Electrical Energy Conversion System

Instructors : **Loïc Queval**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The objective of the course is to present the elements of the electrical energy conversion chain from a DC source to its use for motorization. We will also consider the possibility of variable speed generation used during braking phases. The course has two main parts.

The first part will deal with electric machines used in motorization or in variable speed generation. The aim will be to model these elements and to define the means and conditions for achieving variable speed operation. It will make the link with the following part by showing the impact of electronic sources on the behavior of these machines. The study will also take into account the possibility of variable speed generation used during braking phases.

The second part deals with the electrical energy conversion blocks used for electric motors. The main power electronics converters will be detailed in order to understand the challenges in this area. A focus will be placed on the control of the inverters in order to control the variation in speed and voltage of a motor drive.

Quarter number

SG10

Prerequisites (in terms of CS courses)

No prerequisite

Syllabus

- CM1 (3 HPE, 1 salle, L. Quéval) : Electrical machines
- CM2 (3 HPE, 1 salle, L. Quéval) : Electrical machines
- CM3 (3 HPE, 1 salle, L. Quéval) : Electrical machines
- CM4 (3 HPE, 1 salle, L. Quéval) : Power electronics converter
- CM5 (3 HPE, 1 salle, L. Quéval) : Power electronics converter
- BE (3 HPE, 1 salles, L. Quéval) : Electric conversion chain (Machine + Converter)

Total 18 HPE

Class components (lecture, labs, etc.)

Grading

The report of the BE, completed in group, will be marked.

Resources

Classroom (30 pers) with videoprojection and wifi

Learning outcomes covered on the course

At the end of this course, the student will be able to:

- Define and model the main components of an electric conversion chain
- Understand the operation and control of a DC/AC converter
- Adapt the elements to each other
- Size the components of the motorization and/or generation system at variable speed

Description of the skills acquired at the end of the course

- C1.1 - Study a problem in its entirety, the situation as a whole. Identify, formulate and analyze a problem in its scientific, economic and human dimensions.
- C1.2 - Use and develop adapted models, choose the right modeling scale and simplifying assumptions relevant to the problem.
- C1.3 - Solve the problem with a practice of approximation, simulation and experimentation.
- C2.5 - Master the skills of one of the core trades of the engineer (junior level).
- C3.1 - Be proactive, take initiative, get involved.

3CV3215 – Technological Solutions for Energy Transition and Sustainable Development

Instructors : **Ronan Vicquelin**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

The objective of this course is to propose a global view on the solutions provided and envisaged by the automotive and aeronautical propulsion industries to meet the challenges of the energy transition and the need to reduce carbon dioxide emissions, in particular CO2. For each sector, their specificities regarding environmental issues are presented before detailing an overview of the architectural and technological options considered as well as the main associated physical mechanisms. The institutional and regulatory framework that accompanies the development of these solutions is also introduced.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Automotive industry

The content of this part is built under the prism of energy and its use, which will serve as a common thread in the training.

An introductory section, necessary to fully understand the solutions addressed in the module, will recall some key figures that illustrate in particular:
The automotive industry
The energy produced, the CO2 emissions
A second part will focus on the solutions provided by the automotive industry.
Presentation of the main standards and regulations focused on energy and CO2 emissions. These texts evolve over time and provide frameworks that manufacturers must respect in their developments, in terms of performance to be achieved but also in a time plan
Multi-stage solutions from manufacturers that must be global, from the manufacturing phase to the end-of-life phase, including the vehicle use phase.
A large part, more focused on technological aspects, will present the possible solutions proposed by car manufacturers, in particular through the elements of the powertrain:
Aeronautical propulsion

This part is accompanied by reminders of the basic principles of operation of aeronautical engines, and two focuses on the aeronautical ecosystem beyond the simple framework of the engine manufacturer (institutional / regulatory framework, synthesis and supply of primary energy and alternative energies).

A first part (1 hour) is dedicated to the basic physical principles of the operation of aeronautical engines, in order to provide the basis for understanding the alternative paths mentioned later:
Then, a second part (2h) allows to understand the environmental context of the aeronautical propulsion and the entities and actions involved in the reduction of its environmental footprint:
Once the elements of the context have been addressed, the 3rd part of the module (3h) is dedicated to the inventory of possible architectural options, through the metrics of energy efficiency improvement:

The 4th part (2h), deepening the notion of alternative primary energy, aims at offering an overview of existing and possible options, and their technical, economic and societal stakes
Finally, the 5th part (1h) aims at underlining the strong degrees of interdependence between the propulsion system and the airframe for the future concepts thus envisaged

Class components (lecture, labs, etc.)

Automotive Industry part : 3 sessions of 3h.

Aeronautical Propulsion part : 3 sessions of 3 hours.

A last session for the evaluation of the course.

Grading

The knowledge acquired during the course will be evaluated during a MCQ type test.

Learning outcomes covered on the course

At the end of this module, students will have:

A vision of the environmental context of the aeronautical-automotive sector, societal, normative and institutional, a knowledge of energy flows and its use in a thermal, hybrid or electric motor vehicle, in aeronautical turbomachinery, as well as the guiding principles of the energy efficiency of these systems
A global view of current and future automotive industry solutions (manufacturing, usage, powertrain technologies) as well as possible architectural options to improve the energy efficiency of the aeronautical propulsion system
A knowledge of the main alternative energies applicable to aeronautical propulsion, and the challenges related to their implementation, and the coupling constraints between the propulsion system and the aircraft.

3CV3220 – Control of electrical drive systems

Instructors : **Bruno Lorcet**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

This course is intended for the definition of the association between elements of a conversion chain to achieve a motorization system and its variable speed control.

It begins with the definition of the principles of electrical machine control and the constraints induced by variable speed operation. A second part focuses on the implementation of systems control with a theoretical part followed by an applied part including directed modeling and simulation work. A third part is dedicated to the presentation of industrial achievements with a focus on the aeronautical sector on the one hand and the automotive sector on the other.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Principles of electrical machines control
Electrical machine control architecture - Converter Machine Association - Torque control, speed control
Design constraints - Constant torque operation - Constant power operation

Control of electrical machines
Asynchronous motorization and speed variation
Synchronous motorization and speed variation
Vector controls

Industrial achievements
Aeronautical sector: electric powered aircraft
Naval sector: hybrid propulsion
Automotive sector: hybrid cars

Class components (lecture, labs, etc.)

L1//LT2//LT3//T//L4//L5//Oral

Grading

Oral control in pairs on article preparation and presentation

Resources

Modeling with Matlab-Simulink

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:

- Know the machine control means for a variable speed system
- Define control structures
- Implement the necessary algorithms

3CV3230 – Combustion

Instructors : **Benoît Fiorina**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Combustion is a multidisciplinary science which includes fluid mechanics, chemical kinetics, thermodynamics, heat transfer and possibly two-phase flows. Although the control of fire by man is very old, the beginning of the understanding of the fundamental phenomena of combustion dates from the 18th century. Representing about 80% of the primary energy conversion modes, combustion is present in many industrial applications in the energy sector (thermal power plants, gas turbines), transportation (internal combustion engines, turbojet engines, etc...) and processes (metallurgy, glassmaking, cement works, incinerators, ...). It is also at the heart of many safety issues (fires, explosions, prevention, control, ...) The understanding and control of combustion are therefore particularly important for engineers working in the fields of energy, transportation, processes or safety.
The objectives of the course are to introduce the theoretical foundations of combustion while teaching dimensioning methods useful for an engineer. In particular, the following scientific topics are covered
Thermodynamic characterization of a reactive system: balance, richness, calculation of adiabatic temperature of end of combustion, equilibrium
Chemical kinetics of combustion
Self-inflammation
Structure of laminar flames (deflagration, detonation, stabilization of premixed flames and non-premixed flames)
Introduction to turbulent combustion

Quarter number
SG11

Prerequisites (in terms of CS courses)
none

Syllabus

Session 1 (3h00)
- Introduction to combustion: energy, environmental and industrial context
- Reminder of chemical thermodynamics
- TD: calculation of the adiabatic temperature at the end of combustion

Session 2 (3h00)
- Chemical kinetics of combustion
- Formation of pollutants
- Auto-ignition / Semenov theory
- TD : calculation of auto-ignition delays. Application of Semenov's theory (Matlab)

Session 3 (3h00)
- Deflagration waves and detonation
- Premixed flames
- TD: Determination of laminar flame velocities by theoretical calculation and by experiment

Session 4 (3h00)
- Non-premixed flames
- Introduction to turbulent combustion (part 1)
- TD: application of Burke and Schuman's theory to estimate the temperature distribution in a non-premixed flame

Session 5 (3h00)
- Introduction to turbulent combustion (part 2)
- TD: Application of turbulent combustion modeling concepts for the pre-dimensioning of a reactive furnace.

Class components (lecture, labs, etc.)

Lectures and tutorials

Grading

Two hour written exam

Learning outcomes covered on the course

In his future work environment, the future engineer will have to characterize/size/optimize reactive systems. To do so, he/she will have to make approximations and calculate orders of magnitude. He will have to make mass, chemical species and energy balances. They will have to determine the thermo-chemical equilibrium of a reactive system. In this context, the course aims at acquiring the following skills:

- Know how to pre-dimension a combustion chamber according to the context (industrial sector, type of fuel, targeted power)

  - Establish a global chemical balance for any type of fuel
  - Calculation of the fuel/oil flow rates to ensure a given power
  - Approximate the temperature of burned gases

- Control the thermodynamic and chemical state of a reactive system in various operating configurations

  - Calculate a thermodynamic equilibrium with numerical tools
  - Know the levers that impact the formation of pollutants
  - Know the limits of global balances

- Understand the stakes of combustion in terms of stabilization, ignition and safety of a combustion chamber

  - Establish the equations of a flame. Estimate fundamental quantities (flame speed, auto-ignition delay, ...)
  - Understand the propagation mechanisms of a detonation and deflagration wave. Differentiate a premixed flame from a non-premixed flame.
  - Be aware of the impact of turbulence on combustion

3CV3240 – Turboreactors

Instructors : **Ronan Vicquelin**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

This course is designed to provide the basis for understanding the fundamental concepts required for modern turbojet engine design. It will be divided into three types of content:

Sessions providing the theoretical bases for the modeling of turbojet engines and turbomachinery in general,
Practical sessions (TD) to apply them,
Sessions describing the job of an aeronautical designer, in which the challenges and trade-offs to be achieved will be presented.
The practical applications will be partly realized in session, with Excel (or Python). They will be completed at home and will form the basis of the rating.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

- Session 1: Introduction and Basic Principles
  Energetic notions on flight, orders of magnitude
  Principles of the turbojet engine
  Propulsion, thrust and momentum balance
  Why compress and diverge isobars

- Session 2 : Calculation of a single body single flow jet engine cycle - design :
  Dimensional analysis of a turbo machine
  Definition of motor planes and variables
  Principles and equations (H-S diagram, performance concepts, component by component)
  TD Excel (from geometry, from specification)
  Engine cycle construction, cycle optimization for a specific application
  Work at home for scoring element

- Session 3: Turbojet engine architecture
  What's at stake
  Trade-offs: consumption, pollution, operability, lifespan
  Different architectures for different applications

- Session 4: Calculation of a turbofan turbofan cycle
  Principles and equations
  Definition of motor planes and variables
  TD Excel :
  Construction of a double body engine cycle, optimization of the cycle for a specific application
  Work at home for scoring element

- Session 5: Physics of rotating components
  Dimensional analysis

Euler's equation for rotating machinery
Compressor field, turbine field
TD Excel :
Construction of a simplified compressor field, introduction of the field in the performance model, study of non-adaptation points.
Work at home for scoring element

- Session 6: On the Safran Villaroche site (if possible)
Presentation of the industrial landscape
Organization of the Safran group and link with the professions presented in the course
Turbojet engine design in practice - example: the combustion chamber
V-cycle, 1D to 3D simulations, Validation by tests
Visit of the museum
Some elements of the history of aeronautics
Presentation of the technologies on a real engine in cross-section

Grading

Personal work to be returned

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- Build a simplified performance model, representative of current technologies...
- Describe the trade-offs involved in the design of turbojet engines
- Build a simple compressor field and interpret the characteristics of a real field (ft/flow/efficiency)
- Understand the different stages in the design of a turbojet engine and how the company has organized itself to carry out and control them

3CV3250 – Introduction to orbital mechanics

Instructors : **Sihem Tebbani**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **33**
On-site hours (HPE) : **20,00**

Description

The design of a space mission requires the deployment of multidisciplinary skills. The success of any mission depends on the proper use and mastery of these skills. Among these important concepts and skills, space mechanics and the ability to model the trajectory of a body in a gravitational field are essential. Indeed, skills related to space mechanics are inexorably involved in the design of spacecraft missions (launcher, satellite or interplanetary probe).

The objective of this course is to provide students with the basic skills to understand, analyze and design space missions.
It will address the following general concepts:
- Movement of a rigid body in a gravity field.
- Notion of Keplerian orbit.
- Orbital disturbances
- Orbit estimation.
- Thrusters modeling and orbital maneuvers.
- Orbital rendezvous
- Launchers and interplanetary probes.

Quarter number

SD9

Prerequisites (in terms of CS courses)

There is no specific prerequisites.

Syllabus

- The course will consist of 6 sessions of 3 hours each.
- **Session 1** (3 hours):
  - Panorama of the space sector, examples of space missions
  - Movement of a body in a gravitational field.
  - The notion of Keplerian orbits and Keplerian parameters.
  - Classifications of LEO, GEO, constellations...
- **Session 2** (3 hours):
  - Orbital disturbances, oscillator parameters.
  - Orbit estimation.
- **Session 3** (3 hours):
  - Propulsion and thruster modeling.
  - Orbital maneuvers (Hohmann transfer, orbit and orbital plane correction).
  - **Session 4** (3 hours) Tutorial 1: case of study of keplerian trajectories.
- **Session 5** (3 hours):
  - Orbital rendezvous.
  - Launchers. Endo- and exo-atmospheric trajectories.
  - Interplanetary trajectories.
- **Session 6** (3 hours) Tutorial 2: case of study of non keplerian trajectories.

Class components (lecture, labs, etc.)

Lectures and tutorials.
Several examples of space systems and space missions will be presented.

Grading

Project with a report (by pair).

Course support, bibliography

- S. Tebbani, Transparents de cours (in french).
- CNES, Techniques et technologies des véhicules spatiaux, Cépaduès Editions, 1998 (in french).
- O. Zarrouati, Trajectoires spatiales, Cépaduès Editions, 1987 (in french).
- V. Chobotov, Orbital mechanics, AIAA education series, 1996.
- H. Curtis, Orbital mechanics for engineering students, Elsevier Aerospace Engineering series, 2005.

Resources

Teaching team : Sihem Tebbani
12h of courses and 6h of tutorials.

Learning outcomes covered on the course

At the end of this course, the student will be able to :

- Understand and analyze space missions and the associated technical constraints.
- Understand, model and analyze the trajectory of a spacecraft (satellite, launcher and interplanetary probe).
- Propose a model of the trajectory of a spacecraft according to its mission with respect to technical constraints (type of mission, complexity of the model, desired accuracy, etc).
- Understand and analyze orbit correction and rendezvous maneuvers and associated issues.
- Have a global vision of the space industry and the associated scientific and technical challenges.

Description of the skills acquired at the end of the cours

- Analyze, design and implement complex systems made up of scientific, technological, social and economic dimensions. (C1)
- Acquire and develop broad skills in a scientific or academic field and applied professional areas. (C2)

3CV3260 – Satellite Attitude Control

Instructors : **Thomas Schirmann, Ronan Vicquelin**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

The course aims to give a global vision of the main principles used for satellite attitude control. Its main objectives are the following:

- Knowledge of the space environment and its effects on satellite dynamics
- Understanding the needs in terms of orbit control and attitude control
- Knowledge of the main concepts of attitude control
- Knowledge of the main applications of these concepts to different space missions

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

The course consists of 6 sessions of 3 hours each:

- Session 1: Dynamics and Environment
- Session 2: General Principles of Attitude Measurement
- Session 3: General Principles of Attitude Control
- Session 4: Mission Review
- Session 5: Application to Pleiades
- Session 6: Application to JUICE

Grading

A two-hour written exam

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- Understand the attitude control needs of different space missions,
- To know the disturbances induced by the environment on the attitude of satellites,
- Know the basics of satellite dynamics,
- Know the technologies and equipment used for satellite attitude control,
- Know the main concepts of satellite attitude control,
- Understand their application to some examples of space missions.

3CV3270 – Fatigue of materials and structures

Instructors : **Camille Gandiolle**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

In order to meet the challenges of aeronautics, aeronautical components must ensure performance (less fuel consumption, improved efficiency, which requires in particular reducing the weight of the aircraft) and the safety of the people transported. They must therefore withstand the cyclic stresses of takeoffs/landings, pressurisation/depressurisation and all the mechanical and/or thermal cycles generated by the engine or structure. The new business models are now based on leasing contracts where the manufacturer invoices the flight hour, including maintenance. The control of the durability of the components is then essential.

The aim of this course is to enable students to understand the phenomenon of fatigue damage and to compare the beneficial or aggravating effects of modifications to the component (nature of the material, the production process, the geometry, etc.) or stresses (mechanical or thermal, environment, etc.). The students will be able to dimension a component in fatigue using the two approaches used industrially: fatigue criteria and damage tolerance. The practical applications will be based on aeronautical problems but it should be noted that the sizing approach is transposable to other industrial fields where many fatigue problems also arise, such as land or sea transport, energy or health.

Quarter number
SG11

Prerequisites (in terms of CS courses)
none

Syllabus

1. Introduction. What is fatigue? Damage mechanisms, fatigue under mechanical and thermal loading. Illustration on aeronautical components.
2. Influence of microstructure and defects. Impact of stress concentrations. Effect of the environment. Fatigue damage mechanisms for 3 classes of aeronautical materials (metallic, organic matrix composites and ceramic matrix composites), strategies to improve fatigue resistance.
3. Fatigue sizing: multiaxial fatigue criteria (fixed life or endurance sizing),
4. Taking into account the variability of the loading (loading of variable amplitude, rainflow method, accumulation of damage, vibratory fatigue) and of the material (influence of its defects in particular).
5. Damage tolerance: crack propagation, fracture mechanics reminders, non-destructive testing, taking into account loading variability.
6. Special demands: thermal and contact fatigue cases

Grading

Oral exam at the end of the course (or if more than 10 students Written exam of 1h30)

Learning outcomes covered on the course
At the end of this teaching, the student will be able to :

- Discuss the beneficial or aggravating effects with regard to fatigue resistance of intrinsic and extrinsic effects of the component studied (nature of the material, production process, stresses, environment...).
- Determining the service life of a component subjected to cyclic loading
- Selecting a material with respect to desired fatigue strength

3CV3280 – Compressible flows

Instructors : **Ronan Vicquelin**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Compressible flows are characterized by a strong coupling between pressure, density and velocity. They are involved in many natural phenomena (atmospheric, astronomical) or man-made devices (energy conversion devices, aerodynamic or spacecraft, manufacturing processes, ...).

This course aims to give the basic elements for the calculation of compressible flows in the different fields of application. After a reminder of Thermodynamics, the equations of motion of a compressible fluid will be detailed. A classification of compressible flows will be proposed according to the thermodynamic effects involved. The notion of wave propagation will be at the heart of this teaching, with in particular the role of sound velocity in flows. The notion of shock wave, characteristic of supersonic flows, will also be discussed. Examples from situations from the fields of energy production, aeronautics or space will be used to apply the concepts developed in this course.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

I. Introduction :

- General
- Some examples of compressible flows ;
- Reminders of Thermodynamics;
- Classifications of compressible flows according to similarity parameters and corresponding equations;
- Conservation laws and Navier-Stokes equations for compressible fluids;

II. Shock waves :

- Straight shock waves and Rankine-Hugoniot relations;
- Applications to Pitot-type air intakes;
- Quasi-Monodimensional Flow: Application to the Laval Nozzle;
- Oblique shock waves;
- Inlet applications;
- Reflections between waves and interactions,
- Some examples of pathological cases of reflection or interaction;

III. One-dimensional unsteady flows :

- Notions on hyperbolic systems and wave propagation;
- Riemann's method of characteristics and invariants;
- Applications to the transport cases of scalar functions and solutions of the Burger equation;
- Simple wave flows;
- Application to the calculation of the expansion and limit of the appearance of vacuum;
- Riemann's problem: Application to the solution of the shock tube;
- Application to the road traffic case;

IV. Two-dimensional permanent flows :

- Steady-state equations and changes in variables;
- Characteristics method applied to 2D steady-state flows and Riemann invariants;
- Applications to the computation of over- and understretch jets;
- Application to the sonic injector;
- Application to the calculation of the flow in a nozzle in the form

Class components (lecture, labs, etc.)

The teaching will be organized in 6 sessions. The sessions will be organized in the form of lectures to introduce the concepts and describe the methods, followed by times of application of the methods on examples from concrete situations. The tendency will be to observe a proportion of 50% lectures, 50% tutorials.

Grading

The exam will be written and will last 2 hours, with authorized documents. It will take the form of different independent problems, covering the whole of the subject taught.

Learning outcomes covered on the course

At the end of this teaching, the student..:

- will have learned about the laws of conservation and the system of hyperbolic equations;
- will have acquired skills in calculating flows with shock waves, detents and contact surfaces.
- will be able to apply these skills to the calculation of unsteady plane wave flows, in particular to the solution in a shock or scalar transport tube ;
- will be able to calculate solutions of steady flow in a nozzle and in the jet downstream of a nozzle or injector.

3CV3300 – Advanced Numerics for fluid mechanics

Instructors : **Aymeric Vie**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

In industrial design processes, numerical simulation is used today at all levels in order to describe physical phenomena in time-space in a detailed manner. In order to do so, numerical simulation requires three key elements: a digital mock-up, one or more physical models and a set of numerical methods.

This last element is key. Indeed, the numerical description implies a discretization that leads to numerical errors, which can strongly impact the quality of the simulation. A great deal of attention must therefore be paid to the design and choice of these methods.

In this course, we propose to discover a set of numerical methods adapted to real problems, i.e. applicable to potentially complex geometries with very high accuracy and efficiency requirements. One of the key elements here is the use of unstructured meshes that can be applied to very complex geometries.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Finite Volume Methods (1h30 lecture, 1h30 tutorial)

Numerical approximation and semi-discrete system
Unstructured meshes
Finite Volume Methods
Euler equations in structured mesh (2x1.5 hours lecture, 2x1.5 hours lab)

Riemann problem and discretization
Approximate Riemann solvers
High order methods
Treatment of boundary conditions
Euler equations in unstructured mesh (1h30 lecture, 1h30 tutorial)

Finite volumes applied to Euler equations
Treatment of boundary conditions

Final problem (3h of tutorial)

Implementation of a compressible test case (external aerodynamics)

Grading

At the end of this course, the student will be able to code a high order compressible hyperbolic solver

3CV3310 – Design and manufacturing in aeronautics industry

Instructors : **Ronan Vicquelin, Marie Petrequin**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

The objective of the course is to provide an industrial context for the academic disciplines that contribute to the design and manufacture of aeronautical systems. Because an airplane, a helicopter, a satellite, etc. constitute a complex system whose management is driven from the outset by programmatic, functional and industrial considerations, this course enables students to acquire an aeronautical culture that is as much technical as it is industrial and economic, while being anchored in the current events of the aeronautical world and the major companies that make it up.

What is the starting point for designing an aeronautical system? Why so many different types of aircraft? How do the different technical specialties intervene and interact? How is an aeronautical program managed? How to industrialize it? What are the main stages in the manufacture of an aircraft? How can manufacturing influence design and vice versa? How is the life cycle of an aircraft articulated and how can all the forces necessary for the success of a program be drawn from it?

Through the examination of these questions, students will have the opportunity to grasp the complexity and multidisciplinarity involved in the design and manufacture of aeronautical systems. The lecturers come from diverse backgrounds and have varied experiences, to cover as much as possible of the themes covered in the course.

Quarter number
SG11

Prerequisites (in terms of CS courses)
none

Syllabus

The course consists of interactive lectures and discussions led by engineers specialising in these subjects, based on concrete and real examples from the aeronautical field.

After an introduction to the main concepts and vocabulary elements of aeronautical design, the concept of "system approach" will be presented, its declination for aeronautics and its major stakes: satisfaction of customer needs, regulatory context, complexity of missions, flight safety, taking into account the human factor, etc.

The second major part of the course will be devoted to the industrial part: product life cycle, industrialization, aircraft manufacturing, specificities of the aeronautics industry, organization of production and openness to its major current challenges.

Class components (lecture, labs, etc.)

The course consists of lecture sessions indoors. The last session is devoted to evaluation, which all students attend, always with the aim of broadening their aeronautical culture. A few (non-assessed) TDs may punctuate the course to help students better understand certain concepts through practice (e.g. production organization, MCQ) and to appeal to their "aeronautical common sense".

Multimedia supports: films, images, as well as objects, will be brought during the course to better illustrate the subject.

Grading

A written study report and an oral presentation will allow students in groups to restitute their understanding of a particular technical theme and its impact on the design and manufacture of aeronautical systems. The list of technical themes will be proposed at the beginning of the course and will be anchored in current events in the aeronautical world.

Learning outcomes covered on the course

At the end of this teaching, the following notions will have been addressed:

- Aeronautical culture and airplane
- System approach.
- Functional analysis
- Complex systems architecture
- Flight and system safety
- Taking into account the Human Factor
- Aeronautics Program
- Industrialization
- Major aircraft manufacturing steps and main technologies implemented
- Specificities of the aeronautics industry
- Organization and roles of production support functions
- Aircraft Life Cycle Assessment
- Major challenges in the aeronautical world

3CV3340 – Fluid Structure Interaction

Instructors : **Andrea Barbarulo**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

The problem of Fluid-Structure Interactions is a very vast field which concerns many industrial domains. Guided by a precise dimensional analysis, this course will focus on each of the major families of FSI problems (hydroelasticity, ballooning, vibroacoustics, aeroelasticity, etc.) by introducing step by step the different phenomena that can occur and by proposing different levels of modeling to treat them (analytical or finite element). This progressive and unified approach allows to have a complete vision of the fluid-structure interaction phenomena and to have knowledge of the methodologies and tools to approach them.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

- Introduction to dimensional analysis

- Effect of added fluid mass

- Ballooning

- Compressibility and viscosity effects

- Aeroelasticity

- Effect of added stiffness and damping of the fluid

- Wake and unsteadiness effects

- Adapted numerical methods (variational and finite element formulation for the fluid)

Grading

1 written exam, 2 reports of MatLab lab work done in PC.

Learning outcomes covered on the course

-Provide the theoretical elements necessary for the physical modeling and resolution of fluid-structure interaction problems

-To highlight the main physical phenomena (added mass and stiffness, mode coupling, floating and buckling instabilities, etc.)

-Solve by dimensional analysis, modal analysis and numerical methods, various examples in the fields of aeronautics, civil or marine engineering, electronuclear, biomechanics, etc.

3CV3350 – Spatial launcher design

Instructors : **Andrea Barbarulo**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **65**
On-site hours (HPE) : **39,00**

Description

Under the supervision of space engineers, students dimension and design a launcher that meets given specifications. The objectives of the course are therefore to :

- Acquire technical skills in the space field (rocket propulsion, launch vehicle staging and architecture, aerodynamics, trajectory and performance, sizing for general forces).
- Optimizing a complex system with the interaction of different disciplines
- Acquire good programming practices
- Carry out a preliminary project for a conventional launcher in Phase 0

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

- Space mechanics recalls
- Launcher stage
- Rocket propellant sizing
- Geometry and complete mass balance
- Launcher Aerodynamics
- Trajectory and performance
- General flight efforts

Class components (lecture, labs, etc.)

Tutorial in the computer room
Project carried out in groups of students (pairs or more, to be specified according to the number of students)

Grading

Report and oral defence

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- Use numerical methods of integration and optimization
- Dimensioning a rocket propellant
- Calculate the complete aerodynamics of a launcher
- Calculating general forces on a launcher

3CV3370 – System design project

Instructors : **Antoine Renaud**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **30,00**

Description

The objective is to dimension a system at such a level of complexity and detail that it does not allow one or two people to master the entire subject over the dedicated week. In this project, the students are thus put in a similar situation to design teams working on necessarily multi-disciplinary projects. The project is done in groups of 6-7 students, each student being assigned a role within the team.

The system studied is proposed by MBDA with a strong involvement of its teams. In particular, the project consists in responding to a call for tenders for the pre-dimensioning of an anti-aircraft missile. The students are grouped in teams of 6-7 and occupy one of the following jobs within the team :

- Functional Architect
- Aerodynamic Specialist
- Specialist Guidance Guidance Steering Navigation
- Propulsion Specialist
- Warhead and Structure Specialist
- Self-Directing Specialist

Each team must propose a definition of a missile that will enable the missions described in the specifications to be carried out and that respects the constraints of :

- Platform integration
- System performance (range, manoeuvrability, etc...)
- Cost (each team competes with at least one other team)

Quarter number
SG11

Prerequisites (in terms of CS courses)
none

Syllabus

The content of the course depends on the student's job within the project team. For each profession, the pedagogical tools are as follows:

- A theoretical course of several hours providing the fundamentals necessary for the understanding of the trade.
- One or more software packages with an associated training for each one.
- An accompaniment by at least one MBDA specialist throughout the week.

Class components (lecture, labs, etc.)

The missile project involves a dozen MBDA staff members to provide their expertise and support students throughout the week:

- In the plenary room: all the students are grouped together to attend a general presentation by one of the MBDA speakers.

- By project group: the students are grouped in teams. MBDA speakers are present to accompany them in their reflections.
- By role group: the students are grouped by profession with MBDA specialists in the profession in question.
- By free organization: students choose their own working method. The MBDA lecturers are present in a room to answer their questions.

Grading

Scoring based on observation of the work performed :

- individually (50%)
    - Behavior
    - Understanding/performing the specialist exercise
    - Involvement in group activities
- as a group (50%)
    - Results
    - Design process
    - Quality of presentation

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- Carry out a design process on the scale of a complete system, i.e., analyze and find compromises for the respect of specifications.
- Communicate his needs to the project in order to obtain the necessary information for the realization of his studies.
- Understand the problems of the various professions during the design phase of an anti-aircraft missile.
- Carrying out pre-dimensioning studies for an anti-aircraft missile related to its profession

3CV3380 – Military Aircraft Design

Instructors : **Antoine Renaud, Florent Poleszczuk**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **65**
On-site hours (HPE) : **39,00**

Description

The objective of this course is to place students in a concrete situation of realisation of a preliminary design of a fighter aircraft. Starting from a specification provided by a customer of the company, the students must go through all the steps allowing the dimensioning of the aircraft, from the design of the structure and the layout to the development of the digital flight control laws and the establishment of the performance file. Each stage is guided by theoretical courses applied to the project in order to enable students to understand the technical constraints and compromises necessary for this type of development.

This course is also accompanied by extensive information on existing or former aircraft, allowing an in-depth development of the students' aeronautical culture.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Part 1: Design

Presentation and use of the design rules of a fighter aircraft according to the specifications. Sizing of the wing and airfoil surfaces. Front and rear fuselage layout with definition of the propulsion unit. Establishment of the platform mass balance and study of the centre of gravity.

2nd part: Performance

Presentation and use of the physics of flight mechanics applied to combat aircraft. Calculation of platform aerodynamics by performing lift and drag balances with balancing effects in order to design a platform performance model. Establishment of low speed take-off and landing performance. Determination of a flight domain and a manoeuvrability domain for the aircraft. Performing a complete mission calculation to define the range performance of the platform.

Part 3: Flight Quality

Presentation and use of automatic applied to the design of digital flight control law. Sizing of control surfaces according to precise controllability criteria. Establishment of longitudinal and transverse control laws guaranteeing the compromise between safety and performance. Analysis of system responses to external stresses.

Class components (lecture, labs, etc.)

4 lessons per part in a computer room with the use of CATIA, Perfo2000 (Dassault business software) and Matlab/simulink tools.

Each session lasts 3 hours with an average distribution of 1 hour of lecture and 2 hours of tutorials.

Grading

Evaluation of the project in the form of a synthesis report including the key points of each party.

Learning outcomes covered on the course

At the end of this teaching, the student will have demonstrated his ability to :

- Apply a design office engineering approach to contribute to the design of complex systems
- Understand the issues and trade-offs involved in the design of a fighter aircraft
- Performing low speed and high speed performance calculations of an aircraft from its aeropropulsion model
- To understand the principles of dimensioning of the flight control laws of military aircraft
- Have a broad aeronautical culture

3CV3500 – Project Rozanoff: Client-focused engineering design project

Instructors : **Ronan Vicquelin**
Department : **MENTION AÉRONAUTIQUE, ESPACE ET TRANSPORTS (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **200**
On-site hours (HPE) : **125,00**

Description

This project confronts a group of students with an open engineering problem proposed by an industrial client. While benefiting from the proximity of an industrial player in the sectors of activity covered by the Aeronautics, Space and Transport specialization, the project-group is in contact with an engineer and a teacher from the school in order to understand the client's needs, get organized, implement an approach leading to results that will have to be validated by the client and presented to a non-expert scientific audience. As the project corresponds to a real and open issue, a strong added value of the students' work is expected. Project management is largely left to the students to exercise their autonomy and develop an engineering approach.

Quarter number

SD9 SG10 SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Project work slots are scheduled regularly throughout the year. The organization of work during these sessions is left to the management of the project groups. The life of the project is cadenced by three milestones corresponding to different phases of the project: start, mid-term, end.

Class components (lecture, labs, etc.)

- One group of three students per project with an external client.

Each group is also monitored by a pedagogical referent. This person ensures the efficient running of the project by briefly but regularly exchanging with the group. The pedagogical advisor is not involved in the technical implementation of the project.

Four milestones are common to all projects:

- End of October: assessment of the start-up period. Sending of some transparencies to share the understanding of the subject, the tasks completed or in progress, the planning.
- End of December: report with first results
- Early February: mid-term presentation.
- End of the year: report and deliverables sent to the client, then final presentation.

Grading

- The final grade is determined at the end of the project from several intermediate grades.

- Grade N1 - Project Conduct and intermediate Results
- Grade N2 - Final results
- Grade N3 - Jury Evaluated Defense Note
- Grade N4 - Rated Report Rating by Client

Final Grade = assessed from the rounding of the formula (0.4 x N1 + 0.2 x N2 + 0.2 x N3 + 0.2 x N4)

Learning outcomes covered on the course

- At the end of this teaching, the student will have demonstrated:
- His ability to take on a new open subject requiring a scientific and pragmatic approach.
- A certain maturity in project management: autonomy in management, distribution of tasks, regular exchanges with the customer to understand his needs and meet his expectations.
- Its ability to deliver results by appreciating their value and performance while knowing their limitations through a step back.
- Its ability to deliver accurate, clear and timely deliverables.
- The ability to convey a scientific approach, technical results and well-argued recommendations in writing and orally: the ability to convince.

ENERGY MAJOR (ENE)

3EN1010 – Energy and environmental challenges

Instructors : **Christophe Laux**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This cycle of conferences and visits completes the teachings of the Energy major. The objective is to give an opening on many technical, scientific, economic, societal themes that come into play in the energy transition.
The conférences cover a wide range of topics: environmental issues, energy transition strategies, energy markets, energy precarity, presentation of research activities in the laboratories of the School. They are also an opportunity to meet and exchange with the teachers of the major.
The company visits allow to discover major industrial sites and to meet the actors of these sites.

Quarter number

SD9

Prerequisites (in terms of CS courses)

None

Grading

There will be 6 conferences in this sequence. Validation is based on participation in at least 5 of the 6 conferences.
The visits result in a summary note that will be peer-reviewed.

3EN1020 – Decarbonization of energy production

Instructors : **Martin Hennebel, Herve Gueguen**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **36,00**

Description

The National Low Carbon Strategy established in 2020 by the French government considers that in order to achieve carbon neutrality by 2050, energy production must be nearly decarbonized by this horizon. This decarbonization constitutes a fundamental challenge for the coming years if we consider the time needed to develop new production projects and the lifespan of the installations. This course aims to study the problems associated with the decarbonization of energy production and the technologies that make it possible to envisage it.

Quarter number
SD9

Prerequisites (in terms of CS courses)
none

Syllabus

- Energy system and decarbonization challenges
- Nuclear energy
- Oil and gas and Carbon capture and storage
- Biomass energy
- Solar power
- Wind power
- Hydropower (SES mention)

This program may be adapted depending on the availability of the lecturers.

Class components (lecture, labs, etc.)

Lectures by experts from the economic and academic world

Grading

Final examination which lasts 1h30 in the form of multiple-choice questions covering all the lectures:

- On the Rennes campus, it also includes an evaluation part on the course ‘Power system dynamics for generation (3EN1540)'.
- On the Paris-Saclay campus, it only deals with energy generation.

Resources
Conferences on significant energy sources and their interactions.

Learning outcomes covered on the course

Know the primary sources of energy production and their characteristics.
Understand the issues of decarbonization and the associated systemic complexity.

Description of the skills acquired at the end of the course

C1.1 Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem.
C1.3 Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation

3EN1030 – Heat and Mass transfer

Instructors : **Herve Gueguen, Antoine Renaud**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course aims to train students to model real problems of incompressible fluid mechanics and heat transfer to obtain pre-dimensional values quickly. Focus is put on developing the ability to simplify a real system using specific arguments and by controlling the error committed in order to quickly calculate useful quantities for energy problems such as the efficiency of an exchanger, the heat treatment of a material, the production of energy by a dam or a wind turbine, etc...

Quarter number

SD9

Prerequisites (in terms of CS courses)

None

Syllabus

Session 1: Introduction, mass balance, description of a mixture of species
Session 2: Constraints and deformation rate, local momentum balance (Euler and Navier Stokes), macroscopic momentum balance
Session 3: Local energy balances, Bernoulli theorem, macroscopic balance of mechanical energy, head loss and machine efficiency
Session 4: Modeling an open problem in fluid mechanics
Session 5: The basics of heat transfer: conduction, convection, radiation. Introduction of conduction-convection transfer. First energy balance in stationary and motionless regime. Electrical analogy. Fin and fin approximation.
Session 6: Unsteady conduction and diffusion physics. Energy balance equation. General theorems: superposition theorem and theorem Π. Semi-infinite wall. Case of finite extension media. Space and time diffusion scales.
Session 7: External forced convection: Dimensional analysis. Results of external convection along a flat plate. Internal forced convection: Simplified energy balance. Constant section conduction - regimes and mixing temperature. Results and physical discussion.
Session 8: Modeling an open heat transfer problem

Class components (lecture, labs, etc.)

The course uses a reversed classroom framework. The theoretical notions, similar to those given in the first year Transport Phenomena course, are available in the form of online videos. The face-to-face sessions are 3-hour TD sessions. The first 3 sessions of each part are divided as follows: 1h30 of application and comprehension exercises of the course + 1h30 of open problem solving. The fourth and eighth 3-hour sessions are dedicated to the modeling of an open problem whose results completed at home will be used as a rendering for the evaluation.

Grading

The evaluation will be carried out on two mini-projects in pairs or trinomials launched during the fourth and eighth sessions and aimed at pre-sizing a real system from the tools seen during the course. The output will take the form of a report / calculation note per mini-project comparing the results obtained by the modeling with data available elsewhere.

Resources

No specific means required apart from a personal computer with Internet access.

Learning outcomes covered on the course

At the end of this course, students will be able to model a real problem of incompressible fluid mechanics and heat transfer, and to obtain quantitative pre-dimensioning results.

Description of the skills acquired at the end of the course

C1.2 Use and develop appropriate models, choose the right scale of modeling and relevant simplifying assumptions to address the problem
C2.1 Have a background in a field or discipline related to the basic or engineering sciences.

3EN1040 – Power systems dynamics

Instructors : **Marc Petit**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

As reversible electro-mechanical power converters, the electrical machines are fundamental for the electricity generation, for the development of renewable energy sources (wind), and the the massive electrification of the usages (electric mobility) to reach the decarbonization objectives. In these applications, synchronous and asynchronous machines can be found.
The objective of the course is to introduce tools in order to analyze all the behavioral cases of the two main electrical machines used for energy conversion both in generation mode and in motorization. It is then possible to study the association of these machines with the three-phase electricity network as well as with power electronic converters of VSC type.
The behavior of electrical machines is governed by the phenomena of magnetic couplings between electrical circuits. Thus the first part of the course is responsible for presenting the windings encountered in machines and modeling their magnetic effects.
The second part of the course is dedicated to the presentation of the synchronous machine which is the main generator of electricity and which is also used for motorization. The steady state behavior is first presented and then a study of transient states applies the modeling by operational calculation and transfer functions. The influence of voltage harmonics or the impact of frequency variation can then be predicted from this advanced modeling.
The third part concerns the asynchronous machine which is mainly used in electric motor systems and which is also now found in generation in grid-connected wind turbines. The Park model is established for control applications

Quarter number

SD9

Prerequisites (in terms of CS courses)

Fundamentals in electromagnetism
Fundamentals in AC circuits
Fundamentals in Operationnal calculus (Laplace operator) and in Partial derivations
Electrical powers

Syllabus

Simple structure of the synchronous and asynchronous machines
Magnetic windings and couplings
Windings - MMF - Multipolar windings
Flux captured by a winding
Couplings between coils. case of round rotor and salient rotor
MMF in the alpha-beta frame (Concordia) then the Park frame
Park transformation - Matrix - Vectoriel representation - Complex number representation
Park equations
Mechanical torque

Synchronous Machine
Presentation
Magnetic couplings
Simplification of couplings by Park transformation

Torque calculation
Steady-state operation at synchronism
Transient operation

Asynchronous machine
Presentation
Modeling - Magnetic model in dq reference frame
Torque calculation

Class components (lecture, labs, etc.)

session n°1 : lecture
session n°2 : lecture
session n°3 : exercices or lab
session n°4 : lecture
session n°5 : exercices or lab
session n°6 : lecture
session n°7 : exercices or lab
session n°8 : exercices or lab

Grading

Written examination - 3h (max) - typically organized as follows:
one hour of questions concerning the lectures without any documents
two hours of exercises with authorized lectures documents

Course support, bibliography

Supports:
Presentation of three-phase winding electrical machines - handout - Jean-Claude Vannier
Modelling of the synchronous machine - handout - Jean-Claude Vannier
Transient regimes of synchronous machines - handout - Jean-Claude Vannier

Bibliography:
Transient regimes for rotating electrical machines - Eyrolles - Philippe Barret
Complements on electrical machines - handout - Michel Poloujadoff

Resources

Lectures (4 courses) and presentations of application cases (3 sessions) and one lab session.

Learning outcomes covered on the course

At the end of this course, students will be able to:
understand the magnetic phenomenas governing the behavior of electrical machines.
make the link between the complexity of the windings and the quality of performance obtained.
predict and analyze the steady state and transient behavior of synchronous and asynchronous machines.
define the main components of an electrical energy conversion chain with alternating current machines.

Description of the skills acquired at the end of the course

C1.3 Apply problem-solving through approximation, simulation and experimentation.
C2.3 (milestone 3) integrate and consolidate new skills into a corpus of knowledges

3EN1050 – Materials for energy

Instructors : **Véronique Aubin**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

Structures producing energy must meet two challenges: performance and safety. The materials used in these structures must be capable of meeting these objectives in the best possible way. To do this, they must be able to withstand the stresses exerted on the various components of these structures: mechanical and/or environmental stresses, temperature conditions, even radiation.
The aim of this course is to enable students to understand and identify the physical phenomena at work according to the families of materials and stresses and to know how to choose the appropriate material.

Quarter number

SD9

Prerequisites (in terms of CS courses)

none

Syllabus

The course is organised in two parts. The first part deals with the performance of the structures used in current conditions (wind, hydraulic...) while the second part will focus on structures under intense stress (nuclear fission or fusion power plants, hydrogen fuel cells, thermal power plants...).

Part 1 - structures at ambient temperature
- elasticity, link with the nature of the materials, modelling
- how to build the application-specific material with composite materials,
- installation safety, resistance to cracking

Part 2 - Structures under intense stress (temperature, mechanical stress, environment, irradiation)
- plastic deformation mechanisms
- at high temperatures, creep
- behaviour under irradiation
- durability of structures, influence of the environment

Grading

Written exam of 1h30 at the end of the course

Learning outcomes covered on the course

At the end of this course, students will be able to :
- discuss the beneficial or aggravating effects with regard to the desired performance or the safety of intrinsic and extrinsic effects of the component studied (nature of the material, production process, stress, environment, etc.).
- describe the physical phenomena responsible for the performance of a material in a given application
- choose a family of materials for a given application

3EN1540 – Dynamical Electric Conversion

Instructors : **Herve Gueguen**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description
The objective of this course is to present the main elements of the electricity generation system with their behavior in steady-state and transient states for dynamic studies.
The applications consider the classic case as constant speed electricity generation to newly developed variable speed systems for renewable energy integration.

Quarter number
SD9

Prerequisites (in terms of CS courses)
Electrical Energy – Fundamentals and components

Syllabus

- Presentation of the operation of stators of electric machines - Supply of three-phase currents - Rotating field and characteristics
- Park representation
- Synchronous machines: principles - d,q modeling- torque - steady state - transient
- Fixed frequency grid operation
- Voltage source or VSC type inverters: principles - modeling - control
- Current and torque control
- Variable speed generation - Application to a synchronous permanent magnet generator

Connection of DC sources on three-phase AC grid

Class components (lecture, labs, etc.)
lectures and case studies

Grading
The content of this course will be the subject of specific questions in the exam on the decarbonization of energy course (3EN1020).

Resources
lectures and case studies

Learning outcomes covered on the course
By the end of this course, students will be able to:
- to understand the magnetic phenomena governing the behavior of electrical machines
- to use models and adapt them to the situations encountered in the operation
- to separate the roles of the elements in the conversion chain and to prepare the sizing

understand the challenges of connections between DC and AC networks

Description of the skills acquired at the end of the course
C1.2 Select, use, and develop modeling scales, allowing for appropriate simplifying hypotheses to be formulated and applied towards tackling a problem

3EN1570 – Buildings and net 0 area

Instructors : **Romain Bourdais**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course focuses on one of the most energy-intensive sectors: the building industry (40% of consumption in France and 20% of CO2 emissions). This sector has been undergoing constant change for several years now. It should no longer be considered as a simple consumer but as a real energy player fully integrated into its ecosystem. It must be fully part of a renewed vision of society, where comfort and health are in harmony with energy management. This course, therefore, focuses on both small consumption items within the building and the challenges of new districts (positive energy districts).

The aim of this course is to provide engineering students with all the resources they need to grasp the complexities of building, covering not only the physical aspects (thermal science, notion of comfort) and technological aspects (heat pumps, etc.), but also the sociological (acceptability to occupants), political and economic aspects.

Quarter number

SD9

Prerequisites (in terms of CS courses)

None

Syllabus

Energy challenges - buildings and neighborhoods

Overview of the challenge

- At city level
  - Means of action for a metropolis and a region
  - Deployment of heating networks - technical and economic viewpoints and site visits.
- Inside the building
  - Thermal phenomena
  - Occupant needs
  - Control systems

Class components (lecture, labs, etc.)

This course is organized around lectures. A site visit is planned to understand how a heating network works.

Grading

General knowledge MCQs
Note de synthèse d'un document

Resources

The course is built around a series of lectures on the energy challenges facing the building sector and the questions that engineers need to ask themselves when it comes to deploying efficient solutions, either within a building or in a neighborhood.

Learning outcomes covered on the course

At the end of this course, students will be able to:

- define the significant issues and challenges involved in the building energy transition
- take a critical, justified look at a building transition project

Description of the skills acquired at the end of the course

Identify and acquire new knowledge and skills independently (C2.3)

3EN2010 – Conferences ENE RE

Instructors : **Christophe Laux, Marie-Laurence Giorgi**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

These conferences complete the formal courses of the Energy major. The objective is to give an opening on many technical, scientific, economic, societal themes that come into play in the energy transition. The conferences cover a wide range of topics: environmental issues, energy transition strategies, energy markets, energy precarity, technological innovation, research advances, energy startups... They are also an opportunity to meet and exchange with the professors of the major.

Quarter number

SG10, SG11

Prerequisites (in terms of CS courses)

None

Grading

Pass ou fail. To pass, attendance at at least 5 of the 6 conférences of each sequence is mandatory.

3EN2020 – Geosciences

Instructors : **Benoît Noetinger, Marie-Laurence Giorgi**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **50**
On-site hours (HPE) : **30,00**

Description

The course will introduce the following concepts:
1. Geology, Earth structure, tectonics, sedimentary basins, fmineral formation;
2. Hydrology: water cycle, aquifers, Darcy's law, transient tests, saltwater.
3. Geothermal energy, technical-economic elements, high temperature, low temperature
4. Mineral resources: rare earths, lithium, natural hydrogen
5. Numerical modeling: numerical geology, modeling of underground reservoirs
6. CO2 sequestration

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Class components (lecture, labs, etc.)

Lectures and tutorials

Grading

Individual final written test (1h30)

Resources

Teaching team: Benoit Noetinger (IFPEN), Yves Missenard (Université Paris Saclay), Hermann Zeyen (Université Paris Saclay) et Johann Tuduri (BRGM)

3EN2030 – New technologies

Instructors : **Marie-Laurence Giorgi, Marion CHANDESRIS, Sébastien ROSINI**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **50**
On-site hours (HPE) : **30,00**

Description

The development of intermittent energies in the global energy mix and the transition to low-carbon energies necessary to control global warming raise in a very important way the question of energy storage and the balance between means of production and needs in terms of consumption. Because of the context, energy storage and electrochemical conversion devices are extremely popular and are the subject of both extensive research to improve their performance and a major effort to deploy them in a variety of applications such as mobility, intermittent energy storage and increased energy efficiency. The objective of this course is to provide an exhaustive description of the operating principles and deployment issues of electrochemical energy technologies.

To this end, the main principles of operation of electrochemical conversion systems will first be discussed, with a focus on thermodynamic and kinetic considerations. In a second step, the operation of fuel cells and batteries will be described, in particular the materials and the manufacturing process involved in these systems. The focus will be on SOFC and PEMFC fuel cells and lithium-based batteries.

A description of the simulation tools needed to understand the functioning of these multi-physics systems will be carried out. Finally, the integration of multi-source energy systems in an application will be addressed as well as the notion of hybridization.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

1. Historical and current context of electrochemical generators 3 hrs.
2. Principle of operation of electrochemical generators 6 hrs.
3. Fuel cells and chemical energy storage 6 hrs.
4. Batteries 6 hrs.
5. Multi-scale modeling 6 hrs.
6. Hybrid systems 3 hrs

Class components (lecture, labs, etc.)

Lectures and tutorials

Grading

Individual final written test (1h30)

Resources

Teaching team: Sébastien Rosini (CEA), Marion Chandesris (CEA)
Software tools and number of licenses required: open source software

Learning outcomes covered on the course

At the end of the course, students will be able to :
1. Understand the functioning of electrochemical generators from a theoretical and material point of view.
2. Have an overview of the current and future applications of electrical conversion systems.
3. Propose and evaluate solutions to optimize the energy efficiency of the systems.

3EN2040 – Chemical engineering and ressources

Instructors : **Marie-Laurence Giorgi**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **50**
On-site hours (HPE) : **30,00**

Description

The objective of this course is to provide the knowledge necessary for the design and modeling of facilities encountered in the process and materials industry (unit operations and reactors). These processes are either used in the energy industry or large energy consumers. The course begins with a description of the thermodynamics of solutions and multi-constituent equilibria. It then focuses on chemical reaction engineering (reactor models, notions of chemical kinetics), the sizing of unit operations (distillation, liquid/liquid extraction, permanent contact apparatus), the model of the ideal stage, the height and number of transfer units, the energy balance in a process (optimization, energy efficiency). The course is based on numerous case studies (e.g. nuclear fuel reprocessing, ethanol/water separation or air gas separation).

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Class components (lecture, labs, etc.)

Lectures, tutorials, conferences

Grading

Individual final written test (1h30)

Resources

Teaching team : Marie-Laurence Giorgi (CentraleSupélec, LGPM) and specialists in industry

Learning outcomes covered on the course

At the end of the course, students will be able to:
1. Understand and use phase diagrams
2. Write material and energy balances for process engineering facilities
3. Understand the coupling between these balances and thermodynamic equilibria
4. Design the process engineering facilities in the ideal case
5. Model the gap between the ideal case and the real case

3EN2050 – EI - Geological field mission

Instructors : **Marie-Laurence Giorgi, Benoît Noetinger**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category :
Advanced level :

Description

The objectives of the geological field mission is to make the knowledge acquired in the geology course concrete, by specifying the methods, scales, tools and concepts of field geology which are then interpreted with the tools acquired in the lecture.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Lecture Geology

Class components (lecture, labs, etc.)

Practical work
Travel to an interesting geological site for one week

Grading

work during the week and final report

Resources

Teaching team : Benoît Noetinger (IFPEN), Yves Missenard and Bertrand Saint Bezar (Université Paris Sud)

Description of the skills acquired at the end of the course

possibilité de valider C2, C3, C8

3EN2060 – EI - Energy optimization of processes

Instructors : **Marie-Laurence Giorgi**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The objective of the course is to present the tools necessary to study the process energy optimization, based in particular on a combination of material and energy balances. The concept of exergy or the PINCH method will be presented to estimate the maximum amount of recoverable thermal energy. The course will be based on examples presented by engineers and researchers from industry to show the problems of energy saving and the approach leading to the energy optimization of a production unit. These examples may concern: the development of materials which often requires high temperatures and involves significant amounts of energy; petrochemical processes; processes for separating gases from the air.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Heat and mass tranfers, thermodynamics, chemical engineering

Syllabus

Energy efficiency: why?
Shell & Tubes counterflow heat exchangers
Pinch method according to the TIM (Temperature Interval Method): maximizing recoverable energy, application to a distillation column
Analogy between the TIM method and hot/cold composite curves: interpretation of the large composite curve
Construction of an optimal heat exchanger network (HEN), application to a distillation column
Energy optimization of a production unit of aromatic molecules

Class components (lecture, labs, etc.)

Lectures, case studies and projects

Grading

Personal work in pairs and final presentation

Resources

Teaching team : Denis Bossanne (IFPEN) and Jean-Marc Borgard (CEA)

Learning outcomes covered on the course

At the end of this course, students will be able to 1) implement the PINCH method to find the "MER" (Minimum Energy Requirement) and propose an optimal heat exchanger network on a distillation column, 2) calculate an energy index (EI), 3) propose the implementation of an energy revamping (specific technologies, exchanger train optimization,...) by estimating the impact of the proposed modifications on the EI.

Description of the skills acquired at the end of the course

Validation possible des compétences C1, C3, C4, C7 et C8

3EN2220 – Numerical methods and project

Instructors : **Hervé Duval**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Computer simulation is essential in the optimization of processes to reduce their energy consumption and their environmental impact. To do this, engineers often use commercial software such as AspenPlus to simulate an industrial process (consisting of a set of unit operations) or FLUENT to simulate flows and coupled transfers within a unit operation.
However, before using such complex tools, it is essential to become familiar with multiphysics modeling and numerical methods by developing his/her own "homemade" code: this is the objective of the Numerical Methods and Project course.
Over three days (6 x 3h), students will model and simulate a unit operation by developing their own calculation code. To do so, they will work in small groups. The chosen process will involve the different types of transfer (mass, heat, and momentum). The students will develop a complete approach and will therefore be successively confronted with the physics of the unit operation, the search for data, the calculation of orders of magnitude, the mathematical modelling, the choice of algorithms and numerical schemes, the programming in Python language, the formatting and interpretation of the results. This course will build on the knowledge acquired in the SD9 Energy courses: Advanced Heat Transfers, Heat and Mass Transfer Methodology, and Advanced Fluid Mechanics.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Advanced Heat Transfers, Heat and Mass Transfer Methodology and Advanced Fluid Mechanics (SD9 Energy)

Syllabus

- Presentation of the selected unit operation and the associated industrial issue
  - Air cooling tower of a nuclear power plant, fouling of the packing, prediction of scale deposit
- Analysis of the process and the phenomena involved
  - Orders of magnitude, estimation of characteristic lengths and times, identification of the predominant phenomena
- Modelling of thermodynamic equilibrium between species in solution
  - When process engineering builds on water geochemistry!
- Writing the thermodynamic code in Python
  - Solving the system of algebraic equations by the Newton-Raphson method
- Modelling of species transport and calcite (limestone) precipitation at the packing surface
  - Simplification of the geometry, liquid film falling vertically along a flat plate
- Introduction to the finite volume method
- Writing of the species transport code in Python

- Mesh convergence study and validation of the species transport code
    - Flow between two parallel plates with uniform flux at the wall

- Coupling of the two calculation codes and prediction of the fouling kinetics within the packing

Class components (lecture, labs, etc.)

In groups of 3 to 4, students model and simulate a unit operation in order to answer an industrial problem. During the three days dedicated to this practical work, each group has the time to go deeper into the topic, build its own model and implement it numerically with the methodological support of the supervisors. This support is either individualized or in the form of short presentations on the board.
The deliverables expected at the end of the course are: the source codes in Python, the report (1 per group) presenting the industrial and scientific context, the modelling approach, the mathematical model, its numerical implementation and the answer to the industrial issue.

Grading

The evaluation takes into account: individual attendance, group involvement, relevance and rigor of the modeling, numerical implementation, Python programming (source codes), and the report that presents the work done.

Course support, bibliography

Will be provided:
Slides from the various presentations, selections of scientific articles related to the unit operation studied, summary document on the finite volume method, selection of numericals recipes.

Useful books :
Polycopié CentraleSupélec Mécanique des Fluides ; Tomes I et II ; Sébastien Candel.
Transferts thermiques - Introduction aux transferts d'énergie; 5th edition; authors: Jean Taine, Franck Enguehard and Estelle Iacona; Dunod, Paris, 2014.
Numerical Heat Transfer and fluid flow; 1st edition; author: Suhas V. Patankar ; Taylor & Francis Group, New York, 1980

Resources

- Teaching team: Hervé Duval
- software: Python

Learning outcomes covered on the course

At the end of the course, the students will be able to:
1. identify the different time and space scales taking place in a given process;
2. select the most appropriate scale to solve a given problem;
3. identify and keep the predominant phenomena;
4. reduce the dimensionality and the complexity of a problem;
5. establish a multiphysics model by aggregating knowledge from different scientific fields (fluid mechanics, heat and mass transfers, thermodynamics, chemical kinetics, and chemical engineering);
6. solve PDE using finite volume method in simple geometries;
7. implement the model using Python language;
8. validate the different components of the code and carry out a mesh convergence study
9. keep a critical eye on a model and its limitations.
10. provide a comprehensive presentation of a modelling approach.

Description of the skills acquired at the end of the course

C1. Analyse, design, and implement complex systems made up of scientific, technological, social, and economic dimensions
C2. Acquire and develop broad skills in a scientific or academic field and applied professional areas
C6. Advance and innovate in the digital world
C8. Lead a team, manage a project

3EN2230 – Computational fluid dynamics

Instructors : **Morgan Chabanon, Sébastien Ducruix**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

The objective of this numerical calculation module is to learn how to use a commercial Computational Fluid Dynamics (CFD) software and to use it in the framework for the study of heat and matter transfer.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Heat and mass transfers, fluid mechanics (SD9)

Syllabus

The three first classes alternate between lectures and practical numerical exercises in order to touch upon the following concepts: definition of a computational domain, discretization, main techniques used in the industrial environment, use of the software Ansys Fluent to solve Navier-Stokes equations, turbulence models, boundary conditions.
Finally, the last lectures are devoted to the complete realization of a numerical study in the form of a mini-project. This work will be oriented towards the prediction of heat and mass transfers.

Class components (lecture, labs, etc.)

Lecture and practical work

Grading

Practical work and mini-project

Resources

Teaching team: Sébastien Ducruix (CentraleSupélec, EM2C), Morgan Chabanon (CentraleSupélec, EM2C)
Commercial software Fluent

3EN2240 – Process simulation

Instructors : **Marie-Laurence Giorgi, Daniel Baquerisse**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

The goal of this process simulation module is to carry out a numerical project to make discover process simulation software to students through practice. This software includes unit apparatus models, a thermodynamic database and numerical methods of calculation, and allows to simulate, dimension and optimize the operation of a process. This course is based on one of the main commercial process simulation software. Numerical projects with various objectives and difficulties are proposed to the students to allow them to discover several applications of these softwares and to share experiences at the end of the course.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Transfer Sciences (SD9) and Optimization of the use of resources (SD10) courses

Syllabus

After a presentation of the possibilities and limitations of process simulation softwares (both static and dynamic), students are introduced to the static simulation software by means of an introductory exercise during which they become familiar with the Man-Machine interface and some advanced functionalities. Each group of two to three students will carry out a concrete project with the help of this software that they will have to selected from a range of industrial topics. The project will be carried out taking into account the following constraints of the good functioning of the process, economic constraints and energy constraints.
Finally, the group will have to present its project to the responsible teachers and to the rest of the students.

Class components (lecture, labs, etc.)

Lectures and practical work

Grading

class work, project and final defense

Resources

Teaching team : Daniel Baquerisse, David Bideau and Pascal Ferrari (Orano), Reem Khazem (CentraleSupélec, LGPM)
Commercial software : Aspen Plus

Learning outcomes covered on the course

At the end of this course, the student will be able to :
- Use any commercial process simulation software during his internship or early career,
- Define his expectations regarding process simulation,
- Model a process,
- Develop a critical mind on the results obtained by process simulation software,
- Communicate in a structured way.

Description of the skills acquired at the end of the course

Validation possible des compétences : C1, C2, C6, C7 et C8 (suivant le contenu des projets)

3EN2250 – Experimental work

Instructors : **Hervé Duval**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The objective of this module is to ensure learning of experimental techniques and methods of analysis or characterization of process engineering or materials.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Energy Ressources courses

Syllabus

Each subject will last 18 hours in the laboratories, will be treated in pairs and will be directly related to the work of a researcher, to illustrate his methodological approach, from the bibliographical literature review to the experiments.

The subjects could be in the field of liquid-liquid extraction, distillation, fermentation, production of biofuels, fuel cells, embrittlement from liquid or thermomechanical fatigue.

Class components (lecture, labs, etc.)

practical work

Grading

work during the three days and final report

Resources

Teaching team: PhD students, professors and researchers from 4 laboratories at CentraleSupélec, i.e., LGPM, LMPS, SPMS, and EM2C.

Description of the skills acquired at the end of the course

C1. Analyse, design, and implement complex systems made up of scientific, technological, social, and economic dimensions
C3. Act, engage, innovate within a scientific and technological environment
C9. Think and act as an accountable ethical professional

3EN2260 – Methodology in geosciences

Instructors : **Marie-Laurence Giorgi**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The course is divided into four case studies:

- Case study 1: Numerous energy systems are deployed within the framework of the energy transition and the sustainable development goals defined by the UN (e.g. access to water, access to energy). We can for example cite water pumping systems powered by photovoltaic energy as well as wind farms. The performance and sustainability of these systems strongly depends on their location. It is therefore essential to identify the areas where these systems should be deployed in priority and those where other systems should be preferred. These results are particularly of great interest to decision-makers (e.g. World Bank, UN, governments) and companies. This course presents the methods and data sources that can be used to study the spatial performance of energy systems. Additionally, it details how the results can be presented to support decision-making. The theoretical approach will be applied within the framework of a mini-project/TD (under the Matlab software) on the subject of water access in sub-Saharan Africa.

- Case study 2: Geothermal energy
    - High-temperature geothermal energy
    - Examples of current projects, development, advantages and disadvantages
    - Case study: Quantitative interpretation of injection test data from high-temperature geothermal wells
    - Interpretation of injection test data enables rapid identification of the most permeable reservoir zones, and evaluation of the reservoir's geothermal potential.

- Case study 3: New gases
    - New gases: green gas and hydrogen
    - Green gas development: technical challenges
    - Hydrogen as an energy carrier: examples of the use of hydrogen in renewable energies
    - Case study: Hydrogen storage issues: underground impact and mixing effects

- Case study 4 : Seismic tomography for the design of nuclear structures

Prerequisites (in terms of CS courses)

Geosciences courses (Mention Ressources Energétiques)
Basic knowledge of Matlab

Syllabus

Four case studies described above

Class components (lecture, labs, etc.)

Case studies will be supervised by the teachers.

Grading

Individual written test (1h30)

Resources

Teaching team: Simon Meunier (CentraleSupélec), Arnaud Lange (Storengy), Filippo Gatti (CentraleSupélec)

Learning outcomes covered on the course

manipulation of mapped data, use of large volumes of data, study of the performance of renewable energy systems, support to decision making

Description of the skills acquired at the end of the course

C1, C2, C8

3EN2310 – CO2 capture

Instructors : **Marie-Laurence Giorgi**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

The first objective of this course is to acquire a general knowledge of the management of anthropogenic CO2 in the context of reducing greenhouse gas emissions (in order to contain the CO2 content in the atmosphere at a level that allows the objectives of the " Paris Accord" to be achieved).

The second objective is to deepen the technical and methodological aspects developed in the "CO2 capture and geological storage" option and the conditions for its deployment on an industrial scale. In addition to the technical and economic aspects, societal aspects are also addressed.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

The points discussed will be :
- The place of fossil fuels in an energy mix in transition and decarbonized;
- The carbon budget and the management of anthropogenic greenhouse gas emissions;
- The role of carbon dioxide capture and geological storage: research and innovation topics;
- The different CO2 capture pathways (post-combustion, oxy-combustion, pre-combustion);
- Innovation axes of capture based on industrial research.
- CO2 compression and transport (short introduction on the different transport scenarios) ;
- The geological storage of CO2: principle, state of the art, best practice and major industrial projects in the world ;
- Business approach to storage based on examples of industrial-scale projects illustrating the respective roles of modeling and monitoring storage sites;
- Some economic and regulatory notions;
- Public information and societal acceptability.

Class components (lecture, labs, etc.)

Project work

Grading

The evaluation is based on a team project work including an oral presentation of the project, a report of 10 to 15 pages (maximum) and an individual participation mark. The project can be proposed by the team itself in consultation with the teaching staff. The project aims to consider an integrated CO2 management scenario and should cover most of the course topics. The project can be focused on a specific geographical area taking into account its own specificities or can address a large-scale objective. In all cases, it must take into account the technical and economic aspects but also the societal aspects related to the deployment of CSC technology.

Project presentations are made in the presence of all students and will each be the subject of a debate within the whole group. In other words, the assessment aims first of all to enrich the exchanges on CO2 management more than to give a grade. It is an important pedagogical step in this course.

Note: In case of non-participation in the project, an undocumented exam, lasting one hour, will replace the evaluation described above.

Resources

Teaching team : Jean-Pierre Deflandre and Denis Bossanne (IFPEN)

Learning outcomes covered on the course

- Describe the challenges of decarbonation of the energy mix;
- Propose an approach for implementing the CO2 capture and geological storage pathway for a given scenario;
- Contribute to the societal debate surrounding the reduction of carbon dioxide emissions in the context of the implementation of the " Paris Accord ".

Description of the skills acquired at the end of the course

C2 and C7 skills can be validated

3EN2320 – Porous media

Instructors : **Benoît Goyeau**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

The objective of this course is to study the phenomena of heat and/or species transfer within porous structures present in a large number of environmental (soil pollution, water resources, ...), industrial (separation techniques, hydrogen production, insulation, materials processing, ...) but also in the health sector (bone growth, cancer treatment, ...).

Quarter number

SG11

Prerequisites (in terms of CS courses)

Heat and mass tranfers, fluid mechanics (SD9)

Syllabus

- Introduction
- Establishment of macroscopic conservation equations by volume averaging
- Forced laminar convection in porous media
- Natural laminar convection in porous media
- Introduction to turbulent transfers in porous media
- Fluid/porous interfaces

Class components (lecture, labs, etc.)

Lectures. Exercises will be integrated into the course.

Grading

Written exam of 2 hours if the number of students is more than 10. Otherwise, oral exam.

Resources

Teaching team: Benoît Goyeau (CentraleSupélec, EM2C)

Learning outcomes covered on the course

At the end of this course, the student will be able to identify the basic mechanisms of transfers in porous media, to understand them and to propose models at different scales.

3EN2330 – H2 and fuel cell

Instructors : **Pierre Millet, Marie-Laurence Giorgi**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

Course Objectives:
Introduce the concept of energy and related aspects
Describe energy transformation processes
Summarize thermodynamic and kinetic characteristics of electrochemical cells
Describe the hydrogen economy (scientific and technological issues)
Synthetic fuels : issues and perspectives
Photo-électrochimical processes : issues and perspectives

Quarter number

SG11

Prerequisites (in terms of CS courses)

Basic concepts of thermodynamics
Basic concepts of electrochemistry

Syllabus

Course 1 : Concept of energy and transformation processes
Course 2 : Thermodynamics of galvanic chains
Course 3 : Charge transfer kinetics
Course 4 : Hydrogen production processes
Course 5 : Hydrogen purification processes
Course 6 : Hydrogen storage processes
Course 7 : Fuel cells. (I) principles
Course 8 : Fuel cells. (II) technology
Course 9 : Prospects (I) : synthetic fuels
Course 10 : Prospects (II) : photo-électrochemical processes

Class components (lecture, labs, etc.)

Lectures and tutorials

Grading

Individual written exam (1h30)

Course support, bibliography

J. O'M. Bockris, A.K.N. Reddy, Modern Electrochemistry, Plenum Rosetta, 1970
C.H. Hamann, A. Hamnett, W. Vielstich, Electrochemistry, Wiley-VCH, 1998
F. Barbir, PEM Fuel Cells, Elsevier, 2001
G.A. Olah, A. Goeppert, G.K. Surya Prakash, Beyond Oil and Gas : the Methanol Economy, Wiley-VCH, 2009

Resources

Teaching team : Pierre Millet (Université Paris-Saclay)

Learning outcomes covered on the course

Relate the cell voltage of an electrochemical cell to the Gibbs free energy change of a chemical reaction
Express the rate of charge transfer as a function of exchange current density and symmetry factors
Describe the principles of the hydrogen economy
Describe the basic principles and technological characteristics of water electrolysis, hydrogen permeation, metal hydride formation, fuel cells operation
Describe the limitations of current technologies and discuss challenges and perspectives in terms of improved efficiencies, material science, and processes
Describe some processes for the production of synthetic fuels
Describe the principles of photo-electrochemical cells

Description of the skills acquired at the end of the course

C1 and C2 skills can be validated

3EN2340 – Life cycle analysis

Instructors : **Yann LEROY**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

Life Cycle Assessment (LCA) is a well-known approach to evaluate the environmental impacts of a system (product, process, or service). LCA is defined as the characterization and the quantification of inputs, outputs (material and energy streams), and potential environmental impacts over its entire life cycle. LCA is a standardized approach characterized by:

- quantitative assessment of materials and energy streams and environmental impacts
- multicriteria approach integrating several environmental impacts and damages (global warming potential, abiotic depletion, eutrophication, ozone depletion…)
- life cycle thinking considering the entire life cycle of a system from raw material extraction to disposal and end-of-life strategy.

LCA is widely used for several applications such as Ecodesign, environmental communication (Label), technological and investment decision, policymaking.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Class components (lecture, labs, etc.)

Lectures and workshops

Grading

The evaluation relates to an oral presentation and a technical report of the realized LCA.

Resources

The course alternates lectures and workshops. These workshops consist in performing an LCA in small groups of students.

Learning outcomes covered on the course

- Describe and model the life cycle of a system
- Frame and perform an LCA with respect to ISO 14040 standard
- Model and simulate the environmental performance of a system with an LCA software and its databases
- Understand LCA results

Description of the skills acquired at the end of the course

C1 Analyse, design and build complex systems with scientific, technological, human and economic components
C1.1 Analyse: study a system as a whole, the situation as a whole. Identify, formulate and analyse a system in the framework of a transdisciplinary approach with its scientific, economic, human dimensions, etc.
C1.2 Model: use and develop appropriate models, choose the right scale of modelling and the relevant simplifying hypotheses
C1.3 Solve: solve a problem using approximation, simulation and experimentation
C2 Develop an in-depth competence in an engineering field and in a family of professions
C2.1 Deepen a field of engineering or a scientific discipline
C7 Know how to convince
C7.1 On the substance: Structure your ideas and your argumentation, be synthetic (hypotheses, objectives, expected results, approach and value created)
C9 Think and act as an ethical, responsible and honest engineer, taking into account environmental, social and societal dimensions
C9.2 Analyse and anticipate the possible consequences of the organisations and economic models of the structures to which one contributes

3EN2360 – Isolated microgrids

Instructors : **Marc Petit**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

Electric power systems continue their evolution in the framework of the energy transition and a liberalized market, to enable (i) the integration of renewable energy sources, and (ii) the roll-out of electromobility.
Due to these evolutions, the power systems must be operated closer to their physical limits without jeopardizing the security.
These evolutions mainly impact the distribution grids, as the main part of distributed generation units are connected to MV grids (on-shore wind farms, solar farms) or LV grids (rooftop PV).

The impacts on the power system are at the global level (mainly balancing and peak load), and at a more local scale with voltage drop or overvoltage issues (distribution grid) and congestion (transmission and distribution grids).

More and more, grid operators (TSO and DSO) are encouraged by the regulators to harness the available flexibilities to optimize the investment costs. Flexibiities are related to loads or sources that can be controlled locally or remotely to mitigate a grid constraint. Presently, flexibilities are sold by aggregators that control the flexible assets located at the customers or producers.

the outline of the course is as follows:
- analysis of distribution grids, and their role in smart grids
- flexibility of electric loads
- management and valorization of flexibilities by an aggregator
- electric vehicles: an exemple of flexible asset
- microgrids

Quarter number
SG11

Prerequisites (in terms of CS courses)

Knowledges about electric power system operation is recommended (even if basics are given)

Syllabus

the outline of the course is as follows:
- analysis of distribution grids, and their role in smart grids
- flexibility of electric loads
- management and valorization of flexibilities by an aggregator
- electric vehicles: an exemple of flexible asset
- microgrids

Class components (lecture, labs, etc.)
lectures

Grading

Test with multiple answers questions

Course support, bibliography

Web site of the French regulator : http://www.smartgrids-cre.fr/

European Technology Platform (ETP) SmartGrids :
https://www.edsoforsmartgrids.eu/policy/eu-steering-initiatives/smart-grids-european-technology-platform/

US DoE : https://www.smartgrid.gov/the_smart_grid/

Resources

Lectures with digital slides, use cases

Learning outcomes covered on the course

Understand the main challenges of the smart grids in the context of the energy transition.
Analysis of practical examples related to the smart grids, from a technical and economical point of view

Description of the skills acquired at the end of the course

After this course, the students will better know the drivers of smart grids, and the technical solutions that are deployed.
The students will know some levers of flexibility than can be used for the operation of the power system, and how to valorized these flexibility in the eletricity markets.

skills:
C1.1 (milestone 3)
C2.3 (milestone 3)

3EN2370 – Turbines

Instructors : **Alexis GIAUQUE, Aymeric Vie**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

This course has two main objectives:

The first is to provide the future engineer in energy/aeronautics with the main theoretical tools to understand the flows in turbomachinery. The second is to enable him to implement these principles through a practical activity of compressor pre-sizing.

Four key ideas and principles for the understanding of flows in turbomachinery structure this course. These notions represent stages in the understanding of this type of flow. Each one can be crossed in a sequential way and thus ensures that the future engineer will always progress further in the subject.
Four key ideas and principles for understanding flows in turbomachinery structure this course. These notions represent stages in the understanding of this type of flow. Each one can be crossed in a sequential way and thus ensures that the future engineer will always progress further in the subject.

These notions are the following:

- Meridional and cascade views. These views are intrinsically linked to the flows in turbomachinery. If the meridional view is associated with the conservation of mass, the cascade view allows to consider the energy exchanges within the fluid.
- Velocity triangle. Drawn in the cascade view, it allows to represent directly the changes of direction of the fluid under the effect of the passage through the rotor and the stator. As we will see, it is a powerful tool for the analysis of this type of flows.
- Euler's Theorem of Turbomachinery. This is the fundamental theorem used to link energy exchanges to aerodynamics in turbomachines.
- Radial equilibrium. The preceding points allow a detailed analysis of the flow at the level of the mean radius. The radial equilibrium equation extends this analysis from the root to the tip of the blade.

These notions will be presented in detail in this course. We will also come back to the notions of efficiency, losses and similarity which are also very useful to the engineer. These ideas and principles will be implemented in the pre-sizing of an axial compressor. The work will be carried out on Matlab, in groups of 2 students in order to allow a better acquisition of the skills associated with the preliminary design. The students will have to give a design report evaluated at the end of the course. To allow future engineers to ensure their progress, quizzes will be proposed at the beginning of the sessions. In addition, at the end of the session, time will be reserved for an informal exchange between students and the teacher in the form of questions/answers.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

1 – Introduction - Thermodynamics
- Introduction : Some history, Turbomachinery now and in the near future
- Compressible flows: A refresher crash course, Isentropic flow relations
- Dimensionless quantities and similitude laws : Dimensionless numbers, Similitude laws
- Thermodynamics : Energies, Effective work, Kinetic energy / Work of internal forces, Internal energy / mechanical dissipation, Entropy / Gibbs equation

2 – Aero-Thermodynamics 0D-2D
- Vues and Analysis surfaces : Meridional view, Cascade view
- Thermodynamics : Relative total/stagnation variables
- Transformations : Transformation types, Transformation representation, Evolution of the main variables during compression/expansion
- Efficiency : Isentropic efficiency, Polytropic exponent, Polytropic efficiency, Link between Polytropic and isentropic efficiency, Polytropic efficiency and aerodynamics

3 – Aero-Thermodynamics 2D - Losses
- Euler theorem for turbomachines : Naive derivation, Formal derivation, Rothalpy / Total relative enthalpy
- Velocity triangles : Compressors, Turbines
- Turbines operating characteristics
- Losses in axial compressors : Introduction, Profile losses, Effect of the incidence angle, Other types of losses

4 – Aero-Energetics 3D
- Radial Equilibrium : Naive derivation, Formal derivation, Physical interpretation, Application
- Characteristics in axial turbomachines : Axial compressors characteristics
- Instabilities in Compressors : Stability limit, Stall, Surge, Flutter
- Instabilities-Practical case : Anomaly detection

Class components (lecture, labs, etc.)

Lectures and mini-project

Grading

Written report on the design of a compressor stage.
Knowledge exam in the form of a quizz (30 mins) at the beginning of session 4.

Resources

Teaching team : Alexis Giauque (Ecole Centrale Lyon)

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :
- Understand the flows in turbomachinery.
- Understand and analyze instabilities in turbomachinery.
- Analyze the dimensioning of turbomachinery blades.
- Carry out the preliminary design of a compressor.

3EN2380 – Energy Storage

Instructors : **Marc Petit**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

This course will present the technical and economical issues of storage for the three main energy vectors (electricity, gas and heat). Several use cases will be presented. in the future, the storage will grow to enable the energy transition with more renewable energy sources, and in a context of energy vectors that will be more coupled.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

The content of the course is:
- electrochemical storage (battery and H2)
- integration of storage in electrical power networks
- gas storage
- thermal energy storage

Class components (lecture, labs, etc.)

Lectures + illustration with use cases

Grading

Multiple-choice questions + questions with short response

Course support, bibliography

IRENA report, "Electricity storage and renewables: costs and markets to 2030", https://www.irena.org/costs/Electricity-Storage

Resources

Lectures with digital documents, use cases

Learning outcomes covered on the course

Scientific and techno-economic knowledge of the main technologies for storage

Description of the skills acquired at the end of the course

Identification of the most suited storage solutions for a given situation. Knowledge of the sizing parameters for a storage system.
C1.1 (milestone 3) : analyzing the overall behavior of a complex system with its scientific and economic dimensions
C4.1 (milestone 3) : defining criteria for choosing solutions, taking into account all the identified parameters (technical, economical,...)

3EN2390 – Nuclear thermal-hydraulic engineering

Instructors : **Marie-Laurence Giorgi**
Department : **DOMINANTE - ENERGIE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

Led by two engineers from Framatome, this course presents the job of a design engineer using the example of nuclear thermal-hydraulics. Few equations are presented but many concrete questions that a young engineer is confronted with are addressed: physical analysis, system sizing, safety issues, critical look at the results of calculation codes, ...

The objective is to encourage students to continuously question the rationale behind their technical choices and to make concrete and applied, but rigorous, "engineering reasoning".

The teaching is largely interactive with many exercises. The final test is a professional situation, based on an industrial problem to be solved in teams, taking into account several technical constraints.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Transfer Science

Syllabus

Class components (lecture, labs, etc.)

The course will be divided into 3-hour sessions, taught by two Framatome engineers (Victor Pépin and Jérémy Guermonprez)

Grading

A final oral evaluation will close the course.

Learning outcomes covered on the course

General operation of a nuclear power plant
Physics of pressurised water reactors (PWR)
PWR technology
Operation of a PWR
Nuclear safety and accident studies

Description of the skills acquired at the end of the course

C1, C2, C7

3EN2500 – Project

Instructors : **Marie-Laurence Giorgi**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) :

Description

The synthesis project is a work done in pairs between mid-October and the end of April. The project subject is academic (research activity proposed by a laboratory) or an industrial partners and aims to solve a complex engineering or research subject. The objective is to implement the technical and theoretical notions acquired during the year to solve a problem. The technical and theoretical notions can be for example the different modes of mass and heat transfer, fluid mechanics, flows, process engineering, reactors, materials science and engineering, geosciences. Students can develop tools, theoretical analyses, modelling, simulations and/or experimental work (going beyond the stage of literature review, which is an indispensable but insufficient prerequisite).

Quarter number

SD9, SG10, SG11

Prerequisites (in terms of CS courses)

Energy Resources Courses

Grading

a pre-report, an intermediate defence, a final report and a final defence

Description of the skills acquired at the end of the course

possibility of validating C1, C2, C3, C4, C7, C8 and C9 depending on the subject

3EN3010 – Electrical power networks.

Instructors : **Trung-Dung Le, Martin Hennebel, Marc Petit**
Department : **MENTION RÉSEAUX D'ÉNERGIE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **36,00**

Description

Constantly evolving for more than 100 years, electricity networks are far from being fixed: they develop to meet an ever-increasing demand, are gradually transformed into a competitive market, adapt to environmental constraints news,...
This is how distribution lines are buried, but also decentralized means of production are connected to them: wind turbines, photovoltaic panels, cogeneration, etc.
While energy networks are developing, the loads they supply have also become much more diverse in recent years. In particular, the growing number of non-linear loads (comprising power electronics components) is not without repercussions on the operation of the network. Any energy network can be disturbed by these restrictive loads, but also by incidents (lightning, short circuits, ...) which must always be detected and remedied. The control of disturbed operating regimes and the design of rapid, safe and selective protection systems help to increase both the reliability of energy networks and the quality of the electricity product. These objectives today involve the development and application of a wide variety of techniques, of course linked to electrical engineering, but also to system modeling, digital simulation, signal processing, etc.

Quarter number
SG10

Prerequisites (in terms of CS courses)

- Phasor modelling of Alternating Current signals
- Active, reactive and apparent powers in AC systems
- 3-phases Power Systems
- Electric devices : transformers, Synchronous Generator, Inverter
- Applied Mathematics : Newton-Raphson method, matrix computation.
- Matlab/Python Coding

Syllabus

Power Flow Computation : AC powers, branch and nodes modelling, numerical solving of the equations.
Voltage Control (reactive power compensation, synchronous generators voltage control, voltage collapse)
Frequency Control (Load-Generation Balance, control loops, frequency collapse)
Perturbations (short circuits, harmonics)
Power system dynamics : loss of synchronism
Protections devices.

Grading

Written Exam

Resources

Lectures
Training sessions
Computer simulation tools : Matpower, Jpélec, Matlab-Simulink

Learning outcomes covered on the course

organisation and architecture of an electrical system
Flow distribution: models of network components,
calculating the distribution of power flows in a meshed network.
calculation of voltages in a mesh network
Calculation of frequency variations, and responses of primary and secondary settings.
Calculation of fault currents.
Calculation of harmonic components
Calculation of critical fault clearance time.

Description of the skills acquired at the end of the course

C1 Analyze, design and build complex systems with scientific, technological, human and economic components
C2 Develop in-depth skills in an engineering field and in a family of professions

3EN3020 – Heat and gas networks

Instructors : **Marc Petit**
Department : **MENTION RÉSEAUX D'ÉNERGIE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

this course aims at enlarging the knowledge about energy nerworks with a special focus on gas and heat networks. In the future the electricity, gas and heat networks will interact more and more through power-to-gas and power-to-heat equipments. Additionally, these networks will be a main component of the smart cities.
the main objectif of the course is to explain the physical architectures of the gas and heat networks, and their operation rules to comply their physical constraints

Quarter number

SG10

Prerequisites (in terms of CS courses)

thermal transfert and fluids

Syllabus

1- gas networks
- presentation of the gas energy system (ressources, demand, new gas). presentation of the main structure of the gas markets.
- presentation of the transmission and disribution gas networks. physical laws for the operation of the gas networks. methods for gas networks operation
- use case

2- thermal networks (heat/cold)
- Definition of a heat network with its key components (heating plant, tubes for distribution, substations at the customer side), architecture of the thermal networks.
- physical laws, physical variables (pression, temperature, flow)
- operation methods, losses
- sizing of the pumps and heat/cold plants
- use case

Class components (lecture, labs, etc.)

Lectures and use cases

Grading

Written exam (knowledge questions + exercises)

Resources

Lectures and exrecises

Learning outcomes covered on the course

Architecture and operation of gas and heat networks

Description of the skills acquired at the end of the course

Sizing of a gas and heat network
Methods for operation of gas and heat network

C1.1 (milestone 3) Analyze, design and build complex systems with scientific, technological, human and economic components
C2.3 (milestone 3) : Develop in-depth skills in an engineering field and in a family of professions

3EN3030 – Power systems economics

Instructors : **Marc Petit, Yannick PEREZ**
Department : **MENTION RÉSEAUX D'ÉNERGIE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course aims at presenting the architecture of the energy markets (electricity and gas). The eletricity and gas sectors have changed from a monopolistic organization to a liberalized one. In the electricity sector, the generation and the supply to the customers is liberalized whereas the grid operation remains under a monopolic structure.
The structure of electricity markets must ensure the power system reliability and the balancing between generation and demand at each instant.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Basics about electric power systems

Syllabus

Contents:
- background of economy
- regulation in the electricity sector
- sequences of the electricity markets, wholesale markets
- balancing markets/mechanisms
- grid tariff and investments in power systems
- regulation and gas markets

Class components (lecture, labs, etc.)

Lectures and use cases

Grading

Written exam

Course support, bibliography

"Fundamentals of Power System Economics", 2nd Edition, Daniel S. Kirschen, Goran Strbac, Ed. Wiley, 2018

Resources

Lectures

Learning outcomes covered on the course

Knowledge of the electrical markets architecture and the links with the physical behavior of the power system

Description of the skills acquired at the end of the course

To be able to understand and interpret a regulatory rule for electricity markets
To be able to valorize a generation unit (or storage unit) on the electricity markets
To be able to understand how is built a strategy for energy purchase
Skills C1, C2, C3, C4

3EN3040 – Numerical computation

Instructors : **Philippe Dessante**
Department : **MENTION RÉSEAUX D'ÉNERGIE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Introductions and complements to scientific computing: modeling and optimization of electrical energy systems.
The course is divided into two parts, optimization and methods for solving partial differential equations.
The optimization part will include the construction of models for optimization, stochastic optimization, optimization under constraints, multi-objective optimization, parameter estimation.
The second part on the treatment and solution of partial differential equations will focus on finite difference and finite element methods in static and temporal.
Two practical sessions will complete each part: optimization of battery placement on a distribution network; finite element modeling of an electric machine.
Fields of application: all fields related to electrical energy systems

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

S1 (3H): Models for optimization
S2 (3H): Stochastic Optimization
S3 (3H): Multiobjective optimization
S4 (3H): Constrained optimization + parameter estimation
S5 (3H): Finite Differences
S6 (3H): Finite elements
S7 (3H): Optimization of battery placement on a distribution network
S8 (3H): Use of simulation software for finite element modeling of an electrical machine.

Class components (lecture, labs, etc.)

Lectures, tutorials, personal work on projects

Grading

Written exam / Project defense / TD synthesis

Resources

Lectures, tutorials, personal work on projects

Learning outcomes covered on the course

By the end of the course, students will be able to:
Understand and implement the treatment of an optimization problem.
Use the most appropriate methods for a given problem.
Implement the solution on a computer.
Have a good knowledge of the problems of partial differential equations, especially their resolution by finite difference. Understanding of the operation of a finite element software. Master the stability criteria of discretization schemes.

Description of the skills acquired at the end of the course

By the end of the course, students will be able to:
Understand and implement the treatment of an optimization problem.
Use the most appropriate methods for a given problem.
Implement the solution on a computer.
Have a good knowledge of the problems of partial differential equations, especially their resolution by finite difference. Understanding of the operation of a finite element software. Master the stability criteria of discretization schemes.

3EN3050 – Conferences and visits ENE PEG

Instructors : **Marc Petit**
Department : **MENTION RÉSEAUX D'ÉNERGIE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

Visits are scheduled with the partners of the Mention PEG

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Grading

Writting an individual short note (2 pages)

3EN3110 – Supergrids

Instructors : **Trung-Dung Le**
Department : **MENTION RÉSEAUX D'ÉNERGIE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Alternating current (AC) power grids have taken over direct current (DC) since the battle of currents at the end of the 19th century. But the latter have never completely disappeared and are even increasingly more popular for multiple high-voltage applications (HVDC). This is particularly the case for bulk power transmission over long distances and the connection of offshore wind farms. The HVDC solution overcomes the technical constraints of AC and allows better control of the power flows.

Most existing HVDC grids today are point-to-point. But in the future, they may interconnect with each other to form a continental-scale mesh grid, often referred to as a supergrid. Managing such a grid coexisting with the historic AC network poses many challenges, including low-inertia system control. Indeed, the latter, traditionally supplied by synchronous alternators, is reduced with the increase in the share of converters that interface renewable energy sources with the grid.

The objective of this course is to familiarize the students with DC grids both at the converter level and at the level of grid control and protection.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Power engineering, power electronics, AC power systems:

-Representation of sinusoidal electrical signals in complex plane, phasor diagram.
-Active, reactive and apparent powers. Three-phase electrical systems. Park transformation.
-Composition and operation of transformers
-Operation of synchronous generators
-Power electronics: structure and operation of a converter
-Electrical networks: loadflow, voltage and frequency regulations

Applied mathematics: Newton-Raphson method, matrix calculation. Use of Matlab and / or Python

Syllabus

Session 1 (3h): L. Quéval (CentraleSupélec)
Introduction, war of currents, history of DC grids, types of valves (mercury vapour, thyristor, IGBT), vocabulary, HVDC grid topologies

Session 2 (3h): L. Quéval (CentraleSupélec)
Elements of an LCC-HVDC converter station, elements of a VSC-HVDC converter station (2-level VSC, MMC), comparison of LCC-HVDC and VSC,-HVDC, towards a supergrid?

Session 3 (3h): T.D. Le (CentraleSupélec)
Faults in DC grids, behavior of DC grids (power converters, lines) in the event of a DC fault, DC circuit breakers

Session 4 (3h): T.D. Le (CentraleSupélec)
DC protection strategies and algorithms, fault simulation

Session 5 (1,5h): J. Dai (CentraleSupélec)
Control of DC networks, interaction with AC networks, contribution of power converters to the ancillary services of AC networks

Session 6 (3h): external intervention
Renewable energy and low-intertia networks

Session 7 (1h30): Written exam

Grading

Written exam

Resources

Lectures
Tutorials
Numerical simulation tools: Matlab-Simulink, EMTP-RV

Learning outcomes covered on the course

Know how to carry out a cost-benefit study
Master the control of voltage source converters (VSC), including modular multi-level converters (MMC).
Master the control laws of DC networks, and their interaction with the AC networks
Master the HVDC network protection solutions

3EN3120 – Energy storage

Instructors : **Marc Petit**
Department : **MENTION RÉSEAUX D'ÉNERGIE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course will present the technical and economical issues of storage for two energy vectors (electricity, gas). Several use cases will be presented. in the future, the storage will grow to enable the energy transition with more renewable energy sources, and in a context of energy vectors that will be more coupled

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

The content of the course is:
- electrochemical storage (battery and H2)
- integration of storage in electrical power networks
- gas storage
- valorization of a stationary battery for a grid service

Class components (lecture, labs, etc.)

Lectures + illustration with use cases

Grading

Multiple-choice questions + exercise

Course support, bibliography

IRENA report, "Electricity storage and renewables: costs and markets to 2030", https://www.irena.org/costs/Electricity-Storage

Resources

Lectures with digital documents, use cases

Learning outcomes covered on the course

Scientific and techno-economic knowledge of the main technologies for storage

Description of the skills acquired at the end of the course

identification of the most suited storage solutions for a given situation. Knowledge of the sizing parameters for a storage system.
Skills C1 et C2

3EN3130 – Converter control

Instructors : **Jing Dai**
Department : **MENTION RÉSEAUX D'ÉNERGIE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course focuses on power electronics converters, which interface AC and DC networks or connect generators with renewable energy sources to AC networks. Basic notions in automatic control will be recalled, which will then be used in the modeling of voltage source converters. For the control of the latter, the classic "grid-following" control and the new "grid-forming" approach essential for a low-inertia network will be discussed.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Control Theory course (core module in ST5)

Syllabus

- Reminder of notions in control theory
- Modeling of power electronics converters
- PI control
- Linear quadratic control

Class components (lecture, labs, etc.)

Lectures and Tutorials with applications from the energy and electricity network field

Grading

Tutorial report, 100% of the final grade

Course support, bibliography

Khalil, H.K., “Nonlinear Systems”, 3ème edition, Pearson Higher Education, 2002.
Kailath, T., “Linear Systems”, Ed. Prentice Hall, 1980.
Friedland, B., “Control System Design”, Ed. Mc Graw-Hill, 1986.
de Larminat, Ph., “Commande des Systèmes Linéaires“, Ed. Hermès, 1993.
Soderstrom, T., et Stoica, P., “System Identification”, Prentice Hall, 1989.
Ljung, L., “System Identification – theory for the user”, 2nd ed, PTR Prentice Hall, 1999.

Resources

Teachers team from the Control and Energy Departments.
Experimental devices available in the Control and Energy Departments.

Learning outcomes covered on the course

Modeling and control of power electronics converters, PI control, linear quadratic control

Description of the skills acquired at the end of the course

The module will be an opportunity to deepen the following skills

- C1.3 Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation
- C1.4 Design, detail and corroborate a whole or part of a complex system
- C2.1 Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.

3EN3140 – Embbeded power grids

Instructors : **Marc Petit**
Department : **MENTION RÉSEAUX D'ÉNERGIE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

This course is dedicated to the electrical energy network in the embedded systems: aircrafts, cars, boats
With the growing of electrical systems in embedded systems, the design of the energy networks must be optimized with strong constraints for availability and sizing.
Although their structure is different from public electrical networks, challenges remain: generation-demand balancing, voltage drop, congestion, and perturbations.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Basics about electrical systems

Syllabus

Aircraft:
- introduction to more electric aircraft
- architecture of energy networks in an aircraft
- sizing and behavior

Automotive:
- introduction to more electrioc vehicles (ICE, PHEV, EV)
- architecture of electrical networks in a vehicle (ICE, PHEV, EV)
- sizing and behavior

Boats:
- introduction to all/more electric ships
- architecture of electrocal networks in an aircraft
- sizing and behavior

Class components (lecture, labs, etc.)

lectures and use cases

Grading

Written exam (knowledge questions + exercises)

Resources

Lectures and use cases

Learning outcomes covered on the course

To be able to work on a project dedicated to the sizing of an embedded energy network

Description of the skills acquired at the end of the course

Knowledge of the keys parameters for a sizing
Skills C1 and C2

3EN3500 – Project ENE PEG

Instructors : **Marc Petit, Martin Hennebel**
Department : **MENTION RÉSEAUX D'ÉNERGIE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) :

Description

This project is carried out in parallel with the courses during sequences 9, 10 and 11.
This project is carried out in pairs or triples, and aims to confront students with an engineering and/or research problem.
The stages of the project are based on :
- a bibliography phase and analysis of the state of the art;
- a modelling or design phase;
- a simulation or experimental study phase
- a results analysis phase (from simulations or measurements).

An intermediate report is expected by the end of December, followed by a final report in early April. An oral defense is organized during the last week of the course (before the internship departure).
Regular progress reviews are scheduled with the project supervisors.

Quarter number

SD9, SG10, SG11

Prerequisites (in terms of CS courses)

Basics in electrical and energy engineering, optimization and control sciences. Python and Matlab programming.

Grading

Pedagogical follow-up + report + defence:
Mastery of the subject,
involvement in the project,
quality of the reports,
quality of presentation materials.

Resources

Modelling and simulation tools, experimental models.

Learning outcomes covered on the course

Pose and formalise a scientific problem.
Carry out an analysis of previous work on the subject (state of the art).
Build a model to study a system, define the hypotheses retained.
Make a critical analysis of the results.
Make a clear presentation (ppt + oral presentation) of the project studied.
Write a clear report that allows the reader to follow the scientific approach.

Description of the skills acquired at the end of the course

C1: Analyse, design and build complex systems with scientific, technological, human and economic components
C2: Develop an in-depth competence in an engineering field and in a family of professions.
C3: Act, undertake, innovate in a scientific and technological environment.
C4: Have a sense of creating value for one's company and one's clients.
C7: Know how to convince.
C8: Lead a project, a team

3EN4010 – Digital sciences

Instructors : **Aymeric Vie, Anouar Soufiani**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Introduction to scientific computing; fluid mechanics equations with heat transfers; classification of equations; discretizations in time, problems of stability and convergence.

Differences and finite volumes: linear stability analysis tools; stability of the discretization schemes of the convection terms; parabolic problems with several dimensions (stability of explicit methods, ADI methods); elliptical problems with several dimensions (iterative methods, ADI methods); notions on hyperbolic problems. Treatment of non-linearities (iterative methods, Newton method, Briley-McDonald method).

Pressure treatment: current and vorticity function, iterative methods in primitive variables.

Areas of application: all areas where there are problems related to heat transfer.

Quarter number

SG10

Prerequisites (in terms of CS courses)

no prerequisite

Syllabus

Session 1 (3H): Nature of the equations to solve and classification, numerical implications
Session 2 (3H): Introduction to different classes of numerical methods
Session 3 (3H): Linear stability analysis techniques and first applications
Session 4 (3H): Parabolic equations with several dimensions of space
Session 5 (3H): Elliptic equations, non-linear equations
Session 6 (3H): Algorithms for Navier-Stokes incompressible equations
Session 7 et 8 (3H): Final project

Class components (lecture, labs, etc.)

Lectures, tutorials, homework on the project

Grading

Oral defence

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:

- Simulate on a computer the problems of stationary and unsteady diffusion, isothermal or anisothermal, inert or reactive flows.

- Control the problems and stability criteria of discretization schemes

3EN4011 – Digital Sciences - Electrical Specialty

Instructors : **Philippe Dessante**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The course is divided into two parts, optimization and methods for solving partial differential equations.
The optimization part will include the construction of models for optimization, stochastic optimization, optimization under constraints, multi-objective optimization, parameter estimation.
The second part on the treatment and solution of partial differential equations will focus on finite difference and finite element methods in static and temporal.
Two practical sessions will complete each part: optimization of battery placement on a distribution network; finite element modeling of an electric machine.
Fields of application: all fields related to electrical energy systems.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

S1 (3H): Models for optimization
S2 (3H): Stochastic Optimization
S3 (3H): Multiobjective optimization
S4 (3H): Constrained optimization + parameter estimation
S5 (3H): Finite Differences
S6 (3H): Finite elements
S7 (3H): Optimization of battery placement on a distribution network
S8 (3H): Use of simulation software for finite element modeling of an electrical machine.

Class components (lecture, labs, etc.)

Lectures, tutorials, personal work on projects

Grading

Project defense / TD synthesis

Resources

Lectures, tutorials, personal work on projects

Learning outcomes covered on the course

By the end of the course, students will be able to:
Understand and implement the treatment of an optimization problem.
Use the most appropriate methods for a given problem.
Implement the solution on a computer.
Have a good knowledge of the problems of partial differential equations, especially their resolution by finite difference. Understanding of the operation of a finite element software. Master the stability criteria of discretization schemes.

Description of the skills acquired at the end of the course

By the end of the course, students will be able to:
Understand and implement the treatment of an optimization problem.
Use the most appropriate methods for a given problem.
Implement the solution on a computer.
Have a good knowledge of the problems of partial differential equations, especially their resolution by finite difference. Understanding of the operation of a finite element software. Master the stability criteria of discretization schemes.

3EN4020 – Methodologies and optimization in energy transfer

Instructors : **Mehdi Ayouz**
Department : **MENTION RESSOURCES ÉNERGÉTIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The objective of this course is to confront the students with open problems of heat transfer, inspired by industrial processes, natural phenomena, daily life, ... Students work in groups on different case studies and develop methodological and numerical tools, based on their acquired knowledge and with the help of supervisors.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

Various problems will be treated, related to energy efficiency: Cooling of a plate, insulation of a weather station, dimensioning of the Vulcan engine, heating of an apartment, ...

Class components (lecture, labs, etc.)

Students are divided into groups of about 6 students. Each group is supervised by a teacher. Five 3-hour sessions are planned.

Grading

The students, in pairs or in triads, will work for two hours in the classroom on an open problem. Then, they will give an oral presentation of their work to their supervisor (15 minutes presentation of their results in the form of boards).

Learning outcomes covered on the course

By the end of this course, students will be able to:

Identify the physical phenomena limiting the transfer (calculation of characteristic time, orders of magnitude);
Develop a simple model, coupling different modes of heat transfer;
Formulate simplifying hypotheses adapted to the problem and estimate the error committed;
Choose the relevant modeling scale (time, space...).
Compare the developed simple mod with a numerical model or experiments, depending on the case study

3EN4021 – Methodologies and optimization in energy transfer - thermal specialization”

Instructors : **Sean MCGUIRE**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The objective of this course is to confront the students with open problems of heat transfer, inspired by industrial processes, natural phenomena, daily life, ... Students work in groups on different case studies and develop methodological tools, based on their acquired knowledge and with the help of supervisors.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

Various problems related to energy efficiency will be addressed: cooling a plate, insulating a weather station, sizing the Vulcan engine, heating a flat, etc.

Class components (lecture, labs, etc.)

Students are divided into groups of about ten students. Each group is supervised by a teacher. Five 3-hour sessions are planned.

Grading

The students, in pairs or in triads, will work for three hours in the classroom on an open problem. They will hand in a copy of their work at the beginning of the next session.

Description of the skills acquired at the end of the course

At the end of this course, the student will be able to :

- Identify the physical phenomena limiting the transfer (calculation of characteristic time, orders of magnitude);

- Develop a simple model, coupling different heat transfer modes;

- Formulate simplifying hypotheses adapted to the problem and estimate the error committed;

- Choose the relevant modelling scale (time, space, etc.).

3EN4022 – Methodologies and optimization in energy transfer - Electric specialization

Instructors : **Tanguy Phulpin**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

We would teach how design a converter's chain through several examples and illustrated by 2 lessons. A final project will be evaluated with a report.
8-12 3h lesson: small signal model and command (AV)
15-12 3h projet : command and regulation on PV-battery or inverter-machine (AV – AS)
22-12 3h projet : converter chain for electrical vehicle (TN Renault - TP)
12-01 3h lesson: inductance design (Würth SL)
19-01 3h projet : filter design from scratch (Wurth-SL- TP)
26-01 – 2-02-9-02- 9h projet : PV plants for the french electrical grid (TP-YB-AV et on tourne)

Prerequisites (in terms of CS courses)

Basics of power converter

Resources

All lessons are mandatory
During the project, you have to bring your computer for running simulation

3EN4040 – Combustion

Instructors : **Benoît Fiorina**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Combustion is a multidisciplinary science which includes fluid mechanics, chemical kinetics, thermodynamics, heat transfer and possibly two-phase flows. Although the control of fire by man is very old, the beginning of the understanding of the fundamental phenomena of combustion dates from the 18th century. Representing about 80% of the primary energy conversion modes, combustion is present in many industrial applications in the energy sector (thermal power plants, gas turbines), transportation (internal combustion engines, turbojet engines, etc...) and processes (metallurgy, glassmaking, cement works, incinerators, ...). It is also at the heart of many safety issues (fires, explosions, prevention, control, ...) The understanding and control of combustion are therefore particularly important for engineers working in the fields of energy, transportation, processes or safety.

The objectives of the course are to introduce the theoretical foundations of combustion while teaching dimensioning methods useful for an engineer. In particular, the following scientific topics are covered:

- Thermodynamic characterization of a reactive system: balance, richness, calculation of adiabatic temperature of end of combustion, equilibrium
- Chemical kinetics of combustion
- Self-inflammation
- Structure of laminar flames (deflagration, detonation, stabilization of premixed flames and non-premixed flames)
- Introduction to turbulent combustion

Quarter number
SG10

Prerequisites (in terms of CS courses)
none

Syllabus

Session 1 (3h00)
- Introduction to combustion: energy, environmental and industrial context
- Reminder of chemical thermodynamics
- TD: calculation of the adiabatic temperature at the end of combustion

Session 2 (3h00)
- Chemical kinetics of combustion
- Formation of pollutants
- Auto-ignition / Semenov theory
- TD : calculation of auto-ignition delays. Application of Semenov's theory (Matlab)

Session 3 (3h00)
- Deflagration waves and detonation
- Premixed flames
- TD: Determination of laminar flame velocities by theoretical calculation and by experiment

Session 4 (3h00)
- Non-premixed flames
- Introduction to turbulent combustion (part 1)
- TD: application of Burke and Schuman's theory to estimate the temperature distribution in a non-premixed flame

Session 5 (3h00)
- Introduction to turbulent combustion (part 2)
- TD: Application of turbulent combustion modeling concepts for the pre-dimensioning of a reactive furnace.

Class components (lecture, labs, etc.)

Lectures and tutorials

Learning outcomes covered on the course

In his future work environment, the future engineer will have to characterize/size/optimize reactive systems. To do so, he/she will have to make approximations and calculate orders of magnitude. He will have to make mass, chemical species and energy balances. They will have to determine the thermo-chemical equilibrium of a reactive system. In this context, the course aims at acquiring the following skills:

- Know how to pre-dimension a combustion chamber according to the context (industrial sector, type of fuel, targeted power)
o Establish a global chemical balance for any type of fuel
o Calculation of the fuel/oil flow rates to ensure a given power
o Approximate the temperature of burned gases

- Control the thermodynamic and chemical state of a reactive system in various operating configurations

o Calculate a thermodynamic equilibrium with numerical tools
o Know the levers that impact the formation of pollutants
o Know the limits of global balances

- Understand the stakes of combustion in terms of stabilization, ignition and safety of a combustion chamber

o Establish the equations of a flame. Estimate fundamental quantities (flame speed, auto-ignition delay, ...)
o Understand the propagation mechanisms of a detonation and deflagration wave. Differentiate a premixed flame from a non-premixed flame.
o Be aware of the impact of turbulence on combustion

3EN4050 – Plasma

Instructors : **Aymeric Vie, Christophe Laux**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Plasmas are bound to play a key role in the energy transition. Their extraordinary properties make them particularly suitable for efficient and pollutant-free energy conversion processes.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Quantum and statistical physics

Class components (lecture, labs, etc.)

Combination of courses and applications

Grading

1.5-hr written exam with documents and calculator

Resources

- Lectures on fundamental concepts
- Exercices on energy application: conversion of electrical energy into mechanical energy, cchemical conversion (CO_2 transformation, ...), enhancement of energy production (plasma assisted combustion)

Learning outcomes covered on the course

- understanding of the thermochemical mechanisms generated by plasmas
- ability to apply plasma equations to analyze energy applications and develop new conversion methods

3EN4060 – Electronic conversion systems

Instructors : **Adrien Voldoire**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Teaching electrical energy conversion through power electronics
Applications to electric mobility and the integration of renewable energies

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

Introduction: Need for and interest in power converters
DC/DC converter topologies: choppers
DC/AC converter topologies: full wave inverters and PWM
AC/DC converter topologies: rectifiers and PFCs
Sizing active components, calculating losses and thermal calculations

Class components (lecture, labs, etc.)

Lessons : 9h00
Exercices and simulation : 7h30
Industrial conferences : 1h30

Grading

Continuous evaluation : 25%
Written exam (1H30) : 75%

Course support, bibliography

Course materials available on Edunao

Bibliography :
Alimentations à découpage, Convertisseurs à résonance
by Jean-Paul Ferrieux and François Forrest

Électronique de puissance - 10e édition
by Guy Séguier

Other sources
-Techniques de l'ingénieur
-HAL: French publications
-IEEE : international publisher

Resources

PDF lesson
Exercices and corrections
Digital simulations

Learning outcomes covered on the course

By the end of this instruction, students will be able to:

- Understand energy conversion
- Decipher a new structure
- Design a converter
- Use digital simulation dedicated to power electronics

3EN4070 – Variable speed systems (Electric motor modeling / Regulation / Control)

Instructors : **Amir Arzandé**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The aim of this course is to explain the operation of an electric motorization system allowing variable speed operation with vector control. It presents the structures to realize a variable speed motorization system with electric motors. It is generalized in the case of variable speed generators (wind turbines). The principles of the motors are first recalled and then applied to the motorization based on AC motors which are mainly used for modern electric motorization solutions. The basic physics of structures is presented and the operating principles are described. Modeling is then developed to establish the principles of vector control to perform variable speed drives. It is essentially the association with voltage source type inverters (VSC) which is proposed to study in detail two types of motorization, synchronous motorization and asynchronous motorization.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Basic knowledge in electrical engineering:
Basic knowledge of power electronics:

Syllabus

Description of a variable speed system
Operation of an inverter, its control and its model for control
Synchronous machine, Steady state model, Park transformation, dynamic model and vector control.
IT tutorial on synchronous machine control
Asynchronous machine, Steady state model, Park transformation, dynamic model and vector control
IT tutorial on the control of the asynchronous machine
DC Brushless motor, structure and control
Switch reluctance motor (SRM), structure and control

Class components (lecture, labs, etc.)

CM(1-2) // CA(3) // CM(4-5) // CA(6)

Grading

Students will be assessed on a written exam 2h
supervised written exam

Course support, bibliography

School duplicator: ***Jean-Claude Vannier***

Resources

Classroom with video projector and Wifi
Computer lab, Simulink programming

Learning outcomes covered on the course

Principles of operation of the main motors: synchronous, asynchronous
Principles used for speed variations: electronic converters
Combination of motors with different loads;
General principles: constitution of a motorization chain; Kinematics reminders; Charges
Converters: models for vector control
Synchronous motor - Asynchronous motor, DC Brushless motor, Switch reluctance motor (SRM)
Applications

Description of the skills acquired at the end of the course

At the end of this teaching, the student will be able to:
Understand the operating principle and control of a variable speed system
Dynamic modeling and vector control base
Associate the engine or generator with its converter

3EN4080 – Experimental activities

Instructors : **Laurent Zimmer, Amir Arzandé**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The general objective of the course is to confront the students with real problems of complex energy systems. The goal is to be able to decompose a multi-scale / multi-physics system into more elementary sub-assemblies. These are studied through different experiments in order to understand the fundamental principles and to allow a modeling. All the results are then pooled in order to propose the optimization of a system, which is not necessarily obtained by optimizing the individual subsets. The course is based on a disciplinary knowledge in engineering sciences.

Different systems can be optimized according to the students' skills and interests, ranging from electrical production by wind turbine model (under variable wind conditions), optimization of thermal power by gas combustion, optimization of heat transfers, including the three modes of heat exchange; allowing to touch a large set of real energy systems, while being at a scale that allows a detailed and parametric experimentation

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

After a general presentation of the theme, the students are divided into working groups according to their choices and skills. Their mission is to specialize in a well-defined subset of the global problem in order to understand its functioning. This understanding will be based essentially on experimental results, the exact protocol of which is to be determined. The elaboration of this protocol constitutes an important phase and must be rigorously established. In addition to these experiments, analytical or numerical approaches will be adopted to better interpret the data. The optimization with a precise target will then be performed. In the final sessions, the work of several groups will be combined to optimize a global system. The different groups will first have a restitution work on their thematic before apprehending the system with a larger group.

Class components (lecture, labs, etc.)

The necessary rooms will be both rooms allowing experiments (wind tunnels - combustion experiments) but also computer rooms and a room allowing the projection of documents to a large number. The course will start with a lecture to explain the different steps and processes. Then, the students will carry out practical work, with a close interaction with the supervising staff.

Grading

The evaluation has 3 different phases. The first one consists in the evaluation during the different sessions of tests and analyses. A second mark will be attributed to the quality of the oral restitution of the work: a spirit of synthesis and rigor is expected. Finally, the work of optimization of the system will be returned in the form of a report, where the work of the various sub-groups will also appear. The last two evaluations concern all the members of the groups and sub-groups; however, the first mark will be individual according to the motivation, autonomy, rigor and spirit of initiative demonstrated during the different sessions.

Learning outcomes covered on the course

At the end of this course, students will be able to:

Set up an experimental protocol to understand a system, also based on fundamental knowledge

Be able to optimize elementary systems under constraint.
Be able to give a presentation of their work
Be able to integrate new skills to understand a more complex system.

3EN4090 – ENE Conferences

Instructors : **Aymeric Vie, Christophe Laux**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) :

Description

These conferences complete the formal courses of the Energy major. The objective is to give an opening on many technical, scientific, economic, societal themes that come into play in the energy transition. The conferences cover a wide range of topics: environmental issues, energy transition strategies, energy markets, energy precarity, technological innovation, research advances,... They are also an opportunity to meet and exchange with the professors of the major.

Quarter number

SG10 and SG11

Prerequisites (in terms of CS courses)

None

Grading

To pass this activity, it is required to attend at least 5 of the 6 conférences of the sequence.

3EN4210 – Turbulence

Instructors : **Ronan Vicquelin**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

Turbulent flows are found in most industrial applications. Turbulence favors different types of transfers: momentum, energy, species. These properties can be appreciated (improvement of mixing for example) or penalized (increase of drag and pressure drops). The understanding and modeling of turbulence is, moreover, recognized as one of the most difficult problems in classical physics.

The course addresses several features of turbulent flows: fundamental mechanisms, Kolmogorov cascade, balance equations, case of flows in simple configuration. The different approaches (RANS, LES, DNS) related to the necessary description and modeling of turbulence are also presented and contextualized in the context of industrial and academic applications.

The project started during the session also allows to quickly learn how to set up a RANS calculation with Ansys Fluent software.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Session 1: Fundamental mechanisms, Kolmogorov cascade

Lecture: Introduction & Generalities; Production, Dissipation, Transfer between scales; Energy and dissipative scales; Kolmogorov cascade; RANS LES and DNS approaches
TD : DNS cost, THI decay

Session 2: Averaged balance equations

Lecture: Direct numerical simulation (DNS); Reynolds decomposition; Averaged balance equations (RANS); Closure problem, Reynolds tensor; Turbulent transfer flows (heat, species)
TD : Two-dimensional turbulent jet + Project start-up, part I

Session 3: RANS closure models

Lecture: Reynolds tensor properties; Boussinesq hypothesis, Turbulent diffusion; Turbulent and total/effective viscosity; Gradient diffusion hypothesis; Turbulent Prandtl and Schmidt numbers; Algebraic, one-equation, two-equation models; Standard k-ε model
TD: Continuation of project, part II

Session 4: Parietal turbulent flows

Lecture: Channel flows (Steady state ...); Mechanical and thermal boundary layer structure; Total stress and flow; Friction velocity and temperature; External/internal zone; Viscous sublayer/Tampon zone/Logarithmic zone; Implicit cf(Re) friction law
TD: Continuation of project, part III

Session 5: Spectral analysis and large scale simulation

Lecture: Spectrum of turbulent kinetic energy, dissipation, production; Inertial zone of the spectrum; Transfer between scales; Large scale simulation (LES); Definitions of filters; Filtered equations, subgrid models; Smagorinsky model; Advantages/Disadvantages of LES, wall models and hybrid approaches
TD: Project support

Class components (lecture, labs, etc.)

The grade is linked to a report on the project carried out in pairs.

Grading

The grade is linked to a report on the project carried out in pairs.

Learning outcomes covered on the course

At the end of this course, students will be able to:

Perform a rough dimensioning of some key variables of a turbulent flow
Conduct numerical simulations (RANS) of turbulent flows
Analyze such numerical simulations and judge the relevance of a turbulence modeling approach

3EN4220 – Radiation

Instructors : **Laurent Soucasse, Anouar Soufiani**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **15**
On-site hours (HPE) : **15,00**

Description

Introduction to radiative transfer in semi-transparent media. Targeted applications: nuclear safety, gas and high temperature industries (glass, steel, metallurgy, ...), aeronautic and aerospace propulsion, meteorology, climatology, ...

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Reminders of radiation from opaque bodies: luminance, black body radiation, thermoradiative quantities (emissivity, absorptivity, reflectivity). Transfers between opaque bodies through transparent media (geometric and spectral aspects). Application exercises.
Absorption, emission, volume scattering; self-absorption; optical thickness; radiation transfer equation (different formulations); boundary conditions; radiative flux and radiative power; coupling with the material medium.
Non-scattering radiative transfer in one-dimensional plane geometry (analytical solution): isothermal homogeneous medium, heterogeneous and anisothermal medium.
Limit of optically thick medium; radiative conductivity; limit of optically thin medium; Hottel's evaluation method.
Radiative properties of gases: spectral correlation phenomenon, statistical narrow band model, other models of radiative properties of gases. Radiative properties of particles (Mie theory). Simple applications with diffusion.
Principle of reciprocity. General 3D transfer methods (ray tracing, interpolation, Monte Carlo, ...).

Class components (lecture, labs, etc.)

The course will take the form of five 3-hour sessions, alternating lectures and application exercises. Only one room will be needed.

Grading

The exam will consist of a 15-minute oral. Students will have 30 minutes to prepare their topic before being tested.

Learning outcomes covered on the course

By the end of this instruction, students will be able to:

Identify situations where radiative transfer plays a role (order of magnitude calculations)
Propose simple radiative transfer models

3EN4230 – Two-phase flows

Instructors : **Aymeric Vie**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

Two-phase flows are the basis of many industrial applications, especially in aeronautical or automotive engines. In these engines, the fuel is injected in liquid form and atomizes into fine droplets that will feed the combustion after evaporating. The description, modeling and simulation of such flows is very important to characterize the behavior of combustion chambers.

In this course, we will describe a set of methods for modeling and simulation of such flows, on all the physical stages characterizing it. We will present methods to simulate interface flows, necessary to describe the initial phase of atomization of the liquid jet, as well as those to describe fuel sprays, which focus on the dynamics of evaporating droplets that will feed the combustion.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Session 1 : Physics of injection and atomization

Separated phase / dispersed phase
Primary atomization / secondary atomization
Main dimensionless numbers, examples of liquid jet fragmentation
Sessions 2-3-4 : Infinitely thin interface methods

Overview of the main interface solution methods
Balance equations in two phases
Level-Set method
Volume-Of-Fluid method
Session 5-6-7 : Diffuse interface methods

Averaging methods
Obtaining two-fluid equations
Hyperbolicity
Hierarchy of bi-fluid models and associated physics
Session 8-9-10 : Description of fuel sprays

Lagrangian approach
Eulerian approach
High order method of moments

Grading

Assessment will be based on an article reading in groups of one or two students. This work will be evaluated in the form of an oral presentation and a question and answer session.

Learning outcomes covered on the course

At the end of this instruction, students will be able to:

Understand the hierarchy of methods available to describe a two-phase flow
Choose the modeling method adapted to the two-phase problem encountered

3EN4240 – Components for power converters

Instructors : **Tanguy Phulpin**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

In this lesson, the goal is to become familiar with the power devices and to be able to select and to develop its own power converter.
We will also abord what are the innovations in this field and how can we develop new products for a better efficiency in power electronics because the goal of power electronic is to find a tradeoff between efficiency, price, volume, reliability, ...

Quarter number

SG11

Prerequisites (in terms of CS courses)

- You need to know the electrical characteristics of your circuit (RMS voltage and current, the frequency)

Syllabus

- Global knowledge on power devices
- Active devices such as diodes, thyristor, mosfets, igbt and wide bandgap semiconductors such as gan, sic, diamond
- Magnetic devices such as inductance or transformer
- Capacity, Drivers

Class components (lecture, labs, etc.)

- Power semiconductor (3h)
- Magnetic devices (3h)
- Drivers and PCB and other devices (3h)
- Reliability study in power electronics (3h)
- Design of power converter (3h)
- Perfomances evaluation (3h)

Grading

- Written evaluation (1h30)

Learning outcomes covered on the course

At the end of the lesson, the student will be able to
- Understand and using efficient devices for several applications
- Read a datasheet
- Select the optimal devices for a converter design
- Ensure the reliability

3EN4250 – Power System Disruptions and Reliability

Instructors : **Mohamed Bensetti, Tanguy Phulpin**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

This course provides students with a body of knowledge and modelling tools enabling them to understand the problems associated with the electromagnetic compatibility (EMC) of components and power converters. It aims to make students aware of the conducted and radiated electromagnetic disturbances generated by power converters and the solutions that can be applied to reduce them.

Quarter number

SG11

Prerequisites (in terms of CS courses)

- The elective course " electric energy"

Syllabus

- Basic EMC concepts: sources, couplings, victims and standards
- EMC models of sources and propagation paths for power electronics systems
- Analysis of a case study: Buck chopper, influential EMC parameters
- Study of electromagnetic radiation from power components - radiated emission models
- Design office: Design of near-field shielding using an electromagnetic modelling software tool.

Grading

- written exam 1h30 (50%) + case study report (50%)

Resources

- 8 courses of 1,5h
- 2 Tutorials sessions of 1,5h

Learning outcomes covered on the course

At the end of this course, the student wil be able to :

- Identify an EMC problem
- Propose suitable solutions to reduce the disturbance generated by converters
- Use modelling tools (circuits and 3D) to solve an EMC problem.

Description of the skills acquired at the end of the course

C1.1: Study a problem as a whole and an overall situation
C1.2: Identify, formulate and analyze a problem in its scientific, economic and human dimensions, simplifying hypotheses to deal with a problem
C2.1 : Thoroughly master demain or discipline based on fundamental sciences or engineering sciences.

3EN4260 – Advanced variable speed systems

Instructors : **Marc Petit, Aymeric Vie**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

The aim of this course is to present three major families of applications for variable speed electrical systems: rail traction, industry and marine.

These applications are based on combinations of power electronic converters and electrical machines. It is essential to have a good understanding of each of the functions, their association and their control principles.

This course takes an industrial approach to these systems, using numerous application examples and approaches oriented towards dimensioning.

This course complements the 3EN4070 "Variable Speed Systems" course, which takes a more academic approach to the modelling and control of variable speed systems.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Course on elements of variable speed systems, converters and machines

Syllabus

- detailed struture of a power drive system (PDS)
- classification of electric motors and power electronic converters
- converters with thyristors
- converters with IBGT transistors

- key points for the design of an electric ship
- propulsion systems for electric ships
- concept of "all electric ship"

Class components (lecture, labs, etc.)

Lectures and applications

Grading

The students will be evaluated on the production of a file worked in small groups to deal with one of the subjects proposed by the industrial lecturers.

Course support, bibliography

Presentation supports

Resources

Teaching team :
Henri Baerd - Directeur Technique Projet - GE Energy Conversion
Pierrick Guilloux - Directeur Green Traction - Alstom Tarbes
Xavier Delannoy - Directeur Domaine Technique Propulsion - Naval Group

Learning outcomes covered on the course

Master the different converter-machine combinations and know the advantages and disadvantages of each.

Description of the skills acquired at the end of the course

C1.1 (milestone 3)
C2.4 (milestone 3)
C7.1 (milestone 3)

3EN4270 – Building energy and positive energy building

Instructors : **Aymeric Vie, François Cointe**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

The aim of this course is to present the issues related to the design of positive energy buildings, through numerous examples and international case studies, as well as the calculation and modeling tools specific to the thermal design of buildings, while familiarizing the use through the direct application of these tools to the energy analysis of the Eiffel building where the course takes place.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Heat transfer in buildings:

- Conduction, convection, solar and infrared radiation, psychrometry: modeling and measurement of heat exchange in buildings. Ventilation: modeling and hygiene rules.

Thermal comfort - Building with the climate:

- Thermal equilibrium equations of the body. Effective temperature felt.

- Building with climate: Olgyay and Givoni bioclimatic diagrams. Humid tropical climate, desert climate, Mediterranean climate.

- Adapting traditional housing to the climate and contemporary examples: Martinique's school board, Eastgate Center in Harare, Pearl Academy in Jaipur, girls' school in Gourna, etc.

Designing positive energy buildings:

- Housing: thermal insulation, ventilation, summer comfort and solar protection. Case studies: student housing in the Cité Vert Bois in Montpellier, Bedzed district in London, eco-district in Freiburg...

- Offices and tertiary sector: air conditioning and free-cooling, double-flow ventilation, lighting. Case studies: France Avenue offices in Paris, Mäder College in Voralberg, Federal Building in San Francisco, Elithis Tower in Dijon, Green Office in Meudon, Sonnenschiff in Freiburg, The Edge in Amsterdam...

- Energy production and storage. Case studies: Dymaxion house, Autonomous house project by Alexander Pike, Maison de l'île de France in Paris, Smart green Tower in Freiburg, Cappelle-la-Grande urban network in Dunkirk...

-Complex phenomena and thermal modeling:
- Double skin facades: Trombe and parietodynamic walls, ventilated double skin.

- Heat transfer in a wall in variable regime, thermal inertia and response time, dynamic thermal modeling.

Grading

Study project: Using the tools presented in class and the RE2020 weather files, submit a thesis on the analysis of the summer/winter heat balance and construction choices for a corpus of emblematic buildings, including the Eiffel building (OMA architects) in Saclay.

Description of the skills acquired at the end of the course

Upon completion of this course, students will be able to:

Know the calculation tools in building thermics, and be able to use them for a quick preliminary analysis of the energy needs of a building.

Know and analyze the climatic constraints of a site, and their implication on the design of a building.

To know and find one's way through the construction, ventilation, heating and air conditioning techniques, as well as energy production and storage techniques useful for the design of positive energy buildings, and their adaptation to the building program (housing, tertiary or other)

Know the main examples of sustainable and energy efficient construction in the history of architecture.

3EN4280 – Industrial energetics

Instructors : **Philippe Degand, Aymeric Vie**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

Presentations on the main components of thermal and electrical energy use in industry: power plants, thermal fluids, boilers, steam networks, heat exchangers, industrial heating networks using steam, superheated water or organic fluids.

Special focus on multiple effect evaporation (concentration and production of softened water) with energy and economic comparison between desalination of sea water by osmosis and by evaporation.

Focus on the major cogeneration cycles with highlighting of the parameters of choice (electricity/heat ratio and cost of the electricity produced). Directed exercise allowing to make the comparative figures between the 2 main types of cycles.

Several guided exercises on the different chapters

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

1. Purpose of the course

2. Scope and generalities

3. Thermal fluids

4. Generators of thermal fluids

5. Water treatment

6. Industrial steam heating

7. Industrial heating with pressurized water and organic fluids

fluids

8. Heat exchangers

9. Multiple effect evaporation

10. Combined heat and power generation

10.1. By steam turbine

10.2. By gas turbine

Class components (lecture, labs, etc.)

Four sessions of lectures interspersed with short exercises.

Final session as a guided exercise.

Grading

Written exam, duration 3 hours, in the form of an application exercise, with all documents.

Learning outcomes covered on the course

At the end of this course, students will be able to:

Master the criteria of technical/economic choice between the different energy production systems for industry
Master the dimensioning of these systems, and the orders of magnitude of their main operating indicators
Know the main equipment.

3EN4290 – European energy decarbonisation scenarios

Instructors : **Nicolas Minesi**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

In this course, students will propose a scenario for decarbonizing Europe. Based on the needs of each country (electricity, industrial heat, fuels, etc.), students will choose an energy mix capable of meeting these needs on a year-round basis. This scenario must take into account the geographical reality of each country (finite surface area for installations, unprofitable solar power in the north, no offshore wind power for Switzerland, etc.) and intra-European exchanges. Finally, using approximations, students will estimate the cost of their scenario, adding a further constraint to their rendering.

Class components (lecture, labs, etc.)

- Work in small groups
- Use of shared IT tools

Grading

- Written report
- Oral presentation

Resources

- Documentation

Learning outcomes covered on the course

- Analysis and handling of a global problem
- Application of skills and knowledge acquired during the curriculum

Description of the skills acquired at the end of the course

C1, C3, C6

3EN4500 – ENE EE Project

Instructors : **Sean MCGUIRE, Aymeric Vie**
Department : **MENTION EFFICACITÉ ÉNERGÉTIQUE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) :

Description

The third-year project is conducted in small teams of students between October and April. The subject of the student project is consistent with the themes of the mention Efficacité Énergétique. The project can be one of two types, either a project ‘industriel’ (for example, proposed by a partner of the mention) or ‘academic’ (research activity proposed by a laboratory). The project corresponds to **240 hours of student work**. Approximately 42 half-day slots are reserved for the student to work specifically on their project.

Quarter number

SD9, SG10, SG11

Prerequisites (in terms of CS courses)

none

Grading

The final grade given to each team of students takes into account the quality of the work, the final report (40 pages maximum, not including appendices or references) and the final project defense (20 minute presentation + 10 minute discussion).

Resources

The progress of the project will be monitored by a supervisor who the team of students reports to, usually the person who submitted the project proposal. The different steps put in place by the teaching staff of the mention to monitor the progress of the project are the following:

- **Mid-January**: Each team of students conducts an oral presentation giving a status update to the teaching staff. The team is also expected to present their plan for the completion of the project. The presentation will be 20 minutes total (15 minutes presentation + 5 minutes of discussion with the jury). The presentation is not graded. The presence of the supervisor at this presentation is encouraged but is not required. No written document is required to be submitted at this presentation.
- **Mid-March**: Each team of students writes a final report explaining their work, including the tools used, the methods implemented, and the results obtained. This document should be a maximum of 40 pages (not including appendices and references). This report is graded.
- **Mid-April:** Approximately one week after submitting the final report, each team of students conducts an oral defense of their project. The defense is 30 minutes in duration (20 minutes for the presentation + 10 minutes discussion with the jury). The presence of the supervisor is strongly encouraged but remains unrequired. The presentation is graded.

Learning outcomes covered on the course

At the end of this module, the student will be capable of carrying out a technical project. The student will be capable of formulating the problem addressed by their project, to understand the broader context of this problem and constraints associated with their project, to obtain results and present their work. The project permits the student to apply the theory introduced in their coursework and to further develop their understanding by applying this theory to a real project. At this level of study, the student should show that they can work on their project independently – namely, that they can organize their time and resources, conduct a literature search, obtain information relevant for their project and make progress within their team.

3EN5010 – Technical economic societal challenges of energy sector

Instructors : **Herve Gueguen**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **10**
On-site hours (HPE) : **15,00**

Description

The energy transition is an issue with many components. The objective of this module is to present some of these aspects through complementary presentations of the topics covered in the other teaching units of the SES concentration.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Class components (lecture, labs, etc.)

Lectures and discussions

Grading

Presence control

Resources

Lectures

Learning outcomes covered on the course

These lectures will provide students with elements to understand the complexity of the energy transition.

3EN5020 – Power grids and integration of renewable energy

Instructors : **Pierre Haessig**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **65**
On-site hours (HPE) : **27,00**

Description

Electricity is the most versatile energy carrier and the one that can provide energy services with high efficiency. As a result, its share in the final energy consumption is growing (nearly 20% in 2020 worldwide, a doubling in 50 years). In the 20th century, the development of electricity networks on a continental scale made it possible to provide this energy reliably and cost-effectively, through the construction of large centralized production units (nuclear, coal-fired plants or large dams), at least in the so-called developed parts of the world.
In the 21st century, this organization is challenged by the development of renewable energies (solar and wind) which are inherently distributed resources. Political programs of economic deregulation are also the cause of major changes in the organization of electricity systems. However, and perhaps paradoxically, the temporal and spatial variability of renewable sources increases the interest of grids as a means of energy solidarity between regions. Some contexts encourage instead the development of microgrids, but, although of considerably smaller scale, a large part of their behavior is similar to large grids.

Grids combine technological components, of increasing complexity and performance, with control systems of vital importance (in the broadest sense, which includes the functions of monitoring, coordination, optimization...). It is indeed the effective combination of hardware and software that allows grids to remain in good operating condition most of the time (the reliability of networks is, however, uneven between regions). Indeed, a power system is a large and highly nonlinear system. Maintaining its stability is therefore a complex control problem.
In the vast set of problems related to grids, this course proposes to address:

- the hardware description of power systems: architecture, components, physics principles, effect of renewables
- the analysis of the dynamics of nonlinear systems in general
- the regulation, economical operation optimization (market) and state estimation of power grids

Quarter number
SG10

Prerequisites (in terms of CS courses)

Power systems concepts you need to know (e.g. by having taken the first-year elective “Electrical Energy (ENE)”):
- Analysis of electrical circuits in sinusoidal regime: complex amplitudes and impedances
- Power in AC regime: P (active), Q (reactive) and S (apparent)

Control theory concepts you need to know (e.g. by having followed the ST5 common course on automatic control):
- Modeling of a system by state space equations
- Stability of linear systems
- Regulation of a linear system by a classical controller (ex.: PID)

If some of these concepts were not learned previously, resources will be provided for self-directed learning.

Syllabus

Hardware description of power systems
- Grid architecture: transport, distribution
- Technology of the components: lines & cables, machines, HVDC converters
- Physics principles: models, power flow equation

- Changes associated with new renewable energies and transport electrification

Analysis of nonlinear dynamical systems

- Introduction to nonlinear systems: types of nonlinear systems, nonlinear phenomena (multiple equilibria, limit cycles, chaotic behavior, etc.)
- Small Signals Analysis: time-domain linearizations and approximations
- Systems with static nonlinearities (interconnection of linear dynamics with static nonlinearities)

Control, optimization and state estimation of power grids

- Grid stability and control: control architecture, effect of inertia (e.g. effect of renewables), primary and secondary frequency control, voltage control
- Economic optimization: electricity market
- Grid state estimation: concepts and application to simple static cases

Class components (lecture, labs, etc.)

Teaching is done through lectures and exercises sessions, many of which are computer-based.
Lectures: 16.5 hours, Tutorials: 16.5 hours, Laboratories: 4.5 hours, Evaluation (written exam): 1.5 hours.

Grading

The evaluation of the course is based on 50 % of continuous assessment, in particular during the computer sessions, and 50 % on a final 1.5-hour exam.

Course support, bibliography

MATPOWER User's Manual https://matpower.org/docs/MATPOWER-manual.pdf

Resources

Course staff at CentraleSupélec:

- Stanislav Aranovskiy: Analysis of nonlinear dynamical systems
- Pierre Haessig: Power systems, course supervisor
- Marie-Anne Lefebvre: State estimation in power grids

Lecturer from the industry:

- RTE: technologies and challenges of power transmission systems
- EDF R&D: electricity markets

Required software: Matlab, with Simulink and the open source Matpower toolbox.

Learning outcomes covered on the course

Power systems

- know the architecture of grids and their main components
- know the main grid control mechanisms and the physics behind them
- know the principles of electricity markets
- perform power flow analysis and state estimation on simple grid examples, using computer programs

Analysis of nonlinear dynamical systems

- know essential phenomena of nonlinear dynamic systems
- use linearization techniques to study behavior of nonlinear systems about equilibria
- analyze linear system dynamics interconnected with a static nonlinearity

Description of the skills acquired at the end of the course

The skills described above make it possible to validate the following CentraleSupélec engineering skills:

- C1.2 Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem
- C1.3 Solve problems using approximation, simulation and experimentation
- C1.4 Design, detail and corroborate a whole or part of a complex system

To a lesser extent, the state estimation part relates to competence C6.4 Solve problems through mastery of computational thinking skills.

3EN5030 – Energy dependability

Instructors : **Nabil Sadou**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **36,00**

Description

Throughout their life cycle, power generation, transmission and distribution systems require special attention in terms of safety. Indeed, a safety deficiency can have serious consequences for human and its environment, in addition to seriously affecting energy supply and quality of service. Many of these installations are therefore subject to a strict regulation, requiring a "safety culture". Safety studies are carried out to guarantee reliable and resilient installations and protection systems are defined to reduce or eliminate the consequences of identified failures.
The digitalization of energy systems growths improving it's management and bringing economic benefits. However, this increases vulnerability to cyber-attacks that can damage the grid. So it is necessary to detect and control these possible attacks.
The objective of this course is to present the risk analysis and assessment of operational safety. It will focus on the integration of the safety throughout the life cycle of power systems. It will address the different protection systems to ensure the functional safety and availability of plants et grid.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Probability & Statistics

Syllabus

System :

- Dependability
    - Risk analysis
    - Dysfunctional modeling of complex systems
    - Reliability Models
    - Monte Carlo Simulation for System Reliability and Risk Analysis
- Safety Instrumented Systems

Energy :

-Safety and protection of electrical systems
-Grid and devices
-Information technology (IT) and Cybersecurity
-Safety of power plants

Class components (lecture, labs, etc.)

Lectures-Tutorials

Grading

Written exam

Resources

Lectures - applications (exercises)

Learning outcomes covered on the course

At the end of this course, students will be able :

- to perform a system risk analysis
- to assess the operational safety of a system
- to take into account safety requirements over the system life cycle
- to define the protection systems to be implemented to ensure the functional safety and availability of the installations.

Description of the skills acquired at the end of the course

C1.1 Examine problems in their entirety and beyond their immediate parameters. Identify, C1.4 Design, detail and corroborate a whole or part of a complex system.formulate and analyse the scientific, economic and human dimensions of a problem
C1.2 Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem
C1.4 Design, detail and corroborate a whole or part of a complex system.

3EN5045 – Energy Market

Instructors : **Herve Gueguen**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

This course aims at presenting the structure and strategic challenges of energy markets in France and Europe based on Electricity and gas examples.

Quarter number

SG10

Prerequisites (in terms of CS courses)

basics about energy systems

Syllabus

Electricity:

- electricity market structure
- flexibility mechanisms

Gas

- gas markets
- new vectors
- geopolitical challenges

Grading

Final examination which lasts 30 minutes in the form of multiple-choice questions covering all the lectures.

Resources

lectures

Learning outcomes covered on the course

Knowledge about market mechanisms in order to ensure generation-consumption equilibrium and the evolutions introduced by environmental and geopolitical constraints.

3EN5050 – Data-driven methods for energy forecasting

Instructors : **Stanislav Aranovskiy**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

This course presents the data-driven methods and approaches for the energy transition challenge. The course discusses how data can be used to learn and forecast the energy consumption/production, both off-line and in real time.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Control theory (ST5)

Syllabus

Regression Models for forecasting and prediction
Parametric methods and parameters learning
Evaluating the learning performance
Online parameters estimation
Nonparametric methods

Class components (lecture, labs, etc.)

Lectures and problem-solving sessions.

Grading

Continuous control (80%) and written final control (20%)

Course support, bibliography

1. Les systèmes électriques de demain : Un défi pour la transition énergétique. Lavoisier, 2018.
2. T. Söderström, and P. Stoica. System identification. Prentice-Hall International, 1989.
3. Charu C. Aggarwal, Linear Algebra and Optimization for Machine Learning, Springer 2020

Resources

Lectures and problem-solving sessions. Used software: Matlab.

Learning outcomes covered on the course

Construct regression models for energy forecasting problems
Learn models parameters from data and evaluate the learning performance
Apply nonparametric learning methods for energy forecasting
Estimate and update model parameters based on real-time data

Description of the skills acquired at the end of the course

C2.1 Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.

3EN5060 – Dynamical systems and optimal control

Instructors : **Romain Bourdais**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **55**
On-site hours (HPE) : **33,00**

Description

Beyond technology, one way to reduce the energy impact of systems, or to optimize the production/consumption balance, is to better control these systems, individually and collectively, by integrating, for example, the demands of the energy network. Traditional automatic control tools are insufficient to integrate these energy constraints effectively. This course presents more advanced control techniques, including predictive control, which enable these integrations. The "price" to pay is that these tools require us to move beyond the simple framework of linear systems. This course, therefore, introduces the first elements of non-linear system analysis.

Quarter number

SG10

Prerequisites (in terms of CS courses)

- Modeling (1A)
- Control of dynamic systems (2A)
- Optimization (2A)

Syllabus

A reminder of linear system control
- LQ control
- State observer

Model Predictive Control
- Introduction to predictive control
- Link with LQ control
- Integration of energy constraints
- Relaxations

Non-linear part
- Analysis
- Systems with static nonlinearities (interconnection of linear dynamics with static nonlinearities)

Class components (lecture, labs, etc.)

- Tutorials (27h)
- Laboratory study (12h)

Grading

- Continuous assessment (50%), individual grading
- Laboratory study (50%), group grading

Resources

This course is taught by the department's teaching staff:

- Stanislav Aranovskiy
- Romain Bourdais

Students will be able to apply the strategies both in a simulation environment and on a real model made available at the end of the module.

Learning outcomes covered on the course

At the end of this course, students will be able to:

- implement advanced control strategies, in particular predictive control, which take energy constraints into account
- integrate constraints linked to certain non-linear phenomena: actuator saturation, or power limitation

3EN5210 – Decision making in an uncertain world

Instructors : **Pierre Haessig**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **33,00**

Description

The course “Decision making in an uncertain world” deals with issues related to the transition to a fairer and more durable world regarding energy access. More specifically, it focuses on the **sizing and management of energy networks** exposed to **uncertainty** on two time scales. It also addresses the issue of **conflicting objectives** (e.g. economic cost vs. quality of service).
The long time scale (1 to 25 years) relates to the investment and operating costs required to build and maintain an energy network. Uncertainty comes from future fluctuations in prices and annual demand.
The short time scale (1 hour to 1 week) relates to the operational management of an energy network, in particular the control of energy flows between components. Uncertainty comes from daily variations in weather and demand.
The course addresses the following issues:

- What is the operating principle of a microgrid with renewable energy sources and storage?
- How to formulate the sizing and management of a microgrid as an optimization problem? In particular:
    - How to define quantitative criteria to take into account the economic cost and the environmental impact *over the life cycle*, as well as the quality of service?
    - How to take into account the multiplicity and the often *conflicting* nature of these criteria?
    - How to integrate uncertainty in the optimization process?
- What is the role of energy models in political decision making? How to take into account the multiplicity of stakeholders: users, communities, funders, standards...?

The course provides the theoretical basis for addressing these issues and the related practical knowledge. Students apply the acquired knowledge on exercises and a large project in MATLAB.

Quarter number
SG11

Prerequisites (in terms of CS courses)

- 2nd year optimization course: how to formalize an optimization problem (objective function, constraints)
- Statistics and probability: random variables (cumulative distribution function, quantile)
- Principles of conversion of wind and solar power sources

Syllabus

- Optimization under Uncertainty (9h)
    - Risk preference (neutral vs averse)
    - Formalizing uncertain objective and constraints (expectation, Value-at-Risk)
    - Recourse variables, Two-stage Stochastic Programming, Non-anticipativity constraint
        - Application: Newsvendor problem
    - Multitemporal problems (dynamics), Stochastic Dynamic Programming
        - Applications: Inventory control
- Global & Multiobjective Optimization (4.5h)
    - Deterministic and metaheuristic methods for global optimization (gradient-free, blackbox)
    - Pareto optimality, Pareto front
    - Multiobjective methods (e.g. linear combination)

- Energy outlooks in policy planning (3h)
- Practice: Energy system optimization (15h)

Class components (lecture, labs, etc.)

Courses and small exercises on computer
Large microgrid optimization lab on computer

Grading

Final oral presentation on the microgrid optimization project (about 15 minutes of presentation + 10 minutes of questions)

Course support, bibliography

D. Bertsekas, *Reinforcement Learning and Optimal Control*, Athena Scientific, 2019.
Edwin K. P. Chong and Stanislaw H. Żak, *An Introduction to Optimization*, 4th Edition, John Wiley & Sons, 2013

Resources

Course staff:
- Pierre Haessig (CS): Optimization under Uncertainty
- Nabil Sadou (CS): Global optimization, Multiobjective optimization
- Claire Lucas (Artelys) : Energy outlooks in policy planning

Required software: Matlab with the Optimization Toolbox, the Global Optimization Toolbox and the free toolbox YALMIP.

Learning outcomes covered on the course

At the end of the course, students will:
- Understand the need for global optimization techniques and how a number of such techniques work.
- Understand the formulation of some problems of optimization under uncertainty and know what techniques can be used to solve them.
- Be aware of the specific challenges related to power systems.

Also, they should be able to:
- Choose, adapt and apply global optimization techniques and techniques for optimization under uncertainty to practical problems.

Make decisions concerning power systems combining practical considerations and suitable optimization methods.

Description of the skills acquired at the end of the course

C2.1 Deepen a field of engineering sciences or a scientific discipline

3EN5220 – Change management for energy transition

Instructors : **Marie-Anne Lefebvre**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **21,00**

Description

An ecological and solidarity-based transition involves environmental policy choices whose foundations and economic levers need to be understood without neglecting the question of their societal impact and their acceptability by the various stakeholders.
The objective of the course is to first present the key concepts in environmental and natural resource economics, allowing to understand and analyze the economic problems related to environmental issues.
In a second part, several fundamental concepts from the human and social sciences will be addressed, allowing the accompaniment of this type of project with a view to its acceptability.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Economics of the environment and natural resources
1. Economic dimension of environmental problems
2. Environmental taxation
 Externality and market imperfections
 The different instruments of environmental policy
 Environmental tax policy and redistribution
3. Economic evaluation of environmental policies
 Environmental Economic Valuation
 Cost-benefit analysis
 Some other methods for evaluating environmental policies
4. Natural resources in environmental economics
 Classification of natural resources in economics
 Functioning of natural resource markets

Acceptability, mediation and consultation
1. Basic concepts from the human and social sciences
(rational/social thinking, social representation, knowledge learning, social acceptability, stakeholder engagement, consultation, controversies)
2. Identification of non-technical bottlenecks in the implementation of an energy transition project.
3. Building knowledge for an understanding of these oppositions, conflicts and controversies (individuals, constituted groups, society).
4. Proposing modalities for stakeholder engagement and project governance, adapted to the different phases (from design to operations and closure), with a view to resolving conflicts.

Class components (lecture, labs, etc.)

Conferences
Role-playing workshop

Grading

Written examination / MCQ

Course support, bibliography

Articles published in academic journals in economics will be distributed during the course.
Bontems, P. & Rotillon, G. (2013). *L'économie de l'environnement*. Paris: La Découverte.

Learning outcomes covered on the course

By the end of this course, students will be able to understand and analyze economic problems related to environmental issues.
They will have acquired the basis for negotiating and conducting a project related to energy transition.

Description of the skills acquired at the end of the course

C1.1 - Examine a problem in full breadth and depth, within and beyond its immediate parameters, thus understanding it as a whole. This whole weaves the scientific, economic and social dimensions of the problem.
C2.3 - Rapidly identify and acquire the new knowledge and skills necessary in applicable domains, be they technical, economic or others.
C4.1 - Think in client terms, identify and analyse customer needs, the constraints of other stakeholders as well as include societal challenges.

3EN5230 – Life Cycle Analysis and carbon foot print

Instructors : **Herve Gueguen**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

This course presents the principles and methodologies of life cycle assessment, and in particular the calculation of carbon footprints.

3EN5240 – Energy systems modeling and strategic studies

Instructors : **Herve Gueguen**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

The aim of this course is to present the principles and tools of modeling and analysis for prospective studies on the evolution of energy systems.

Prerequisites (in terms of CS courses)

None

Resources

Courses & conferences

Learning outcomes covered on the course

Understanding modeling and simulation mechanisms

Description of the skills acquired at the end of the course

C1

3EN5500 – Industrial or Research Project

Instructors : **Herve Gueguen**
Department : **MENTION SYSTÈMES & ÉNERGIE DURABLE (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Quarter number

SD9, SG10, SG11

Prerequisites (in terms of CS courses)

none

Grading

The evaluation will be based on :

- the consideration and formalization of the problem
- the general organization of the project and communication within the team
- the precision and rigor of the technical exchanges with the supervisors
- the quality of the work, results and deliverables of the project.

- These will be formalized by
  - an intermediate evaluation at the end of term10 (25%)
  - a final evaluation at the end of term 11 (75%)

LARGE SCALE INTERACTIVE SYSTEMS MAJOR (GSI)

3GS1010 – Complex Systems Engineering

Instructors : **Marija JANKOVIC**
Department : **DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Increasing complexity of systems is not allowing for their ad hoc design and development. It is necessary to organize and manage a systematic resolution of related challenges in particular deploying a Systems Engineering approach. Systems Engineering represents a well-established industrial and scientific approach supporting collaborative and concurrent design of systems. This approach is based upon the integration of the whole life cycle into systems design and its operation and evolution management.
The objective of this class is to introduce students to state of the art practice in SE as well as touch upon advanced methodologies aiming and managing systems design and development. It is necessary to have notions on System modelling in order to follow this class. The aim is to prepare students to be operational in the industrial setting but also to discuss challenges and current state of the art developments.

Quarter number

SD9

Prerequisites (in terms of CS courses)

none

Syllabus

Students will be put in situation (complex project management) in order to learn and deploy complex system engineering. "Flipped classrom" approach will be used to suppor student in learning and deploying several engineering methodologies.

Subjects that will be adressed are the following:
1. Introduction of Systems Engineering, SE processes

2. System architecting, definition, introduction of the notion of the concept, functional modelling, structural modelling, interface management and definition
Introduction to the notion of the system architecture, Introduction to the notion of the function and function modelling, Introduction to the notion of the structure and structural modelling, Interface definition and their management, Introduction to the notion of the standardization and modularity, Link with the requirements management

3. Decision making and Trade-space management
Introduction to the notion of trade-offs and their management,

4. Introduction to the Verification and Validation process
Introduction to the notion of Verification and Validation, Link with the requirements engineering

Grading

Project based evaluation

Course support, bibliography

- INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities, 2016
- NASA Systems Engineering Handbook, 2016
- “Trade-space exploration”, Crawley, MIT Press.

Learning outcomes covered on the course

-Understanding of the development process, phases and activities
-Understanding of different industrial positions and their involvement in the SE
-Understanding of system architecting and different types of modelling allowing for information gathering and exchange (System architecture frameworks, NAF, DAF, TOGAF, etc.)
-Deployment of system analyses and optimization
-Deployment of system architecture decision support

Description of the skills acquired at the end of the course

C1 - Analyze, design, and build complex systems with scientific, technological, human, and economic components
C4 - Have a sense of value creation for his company and his customers
C7 - Know how to convince
C8 - Lead a project, a team

3GS1030 – Introduction to operations management and supply chain

Instructors : **Bruno Croizat, Evren SAHIN**
Department : **DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The course introduces students to Operations Management and Supply Chain by developing an overview of issues and problems related to the design, monitoring and management of production and distribution systems for goods and services:
- Understand the challenges and issues of production and distribution of goods and services (from the most strategic to the most operational ones)
- Develop knowledge of the production systems of goods and services, types and characteristics, vision, objectives, monitoring, structure and organization, management, today and trends…. Industry 4.0
- Show the diversity of dimensions to be integrated: health, security, finance, environment, social and human
- Identify the need to improve systems to adapt to changes in the environment (social, regulatory, media, ...) and the expectations of customers, staff
- Understand how the decisions / processes are articulated in order to design and manage production and distribution systems to meet the identified challenges and issues - the organizational and process dimensions of the SCM

Quarter number

SD9

Prerequisites (in terms of CS courses)

Having taken an elective course or an engineering challenge term in connection with Operations & Supply Chain Management would be a plus.

Syllabus

- Introduction to the customer-oriented supply chain
- Typology of supply chains, products, services and customers
- Process, decisions, organization and management
- Performance indicators
- Organizations and processes, management
- Typical operating account, OPEX / CAPEX
- Need for improvement
- Design of an agile and resilient supply chain
- Industrial network - Supplier network
- Distribution network
- Planning and management of flows in a supply chain
- Industry of the future, 4.0, digital and social transformation
- Technologies and usages

Class components (lecture, labs, etc.)

Lectures and industrial experiences
Exercices and Case studies

Grading

Continuous assessment and team project at the end of the course

Course support, bibliography

- Lee Krajewski, Larry Ritzman, Christopher Townley, Jacky Renart, *Management des opérations*, 2e éd., Pearson, 2010.
- Stephen Robbins, David DeCenzo, Mary Coulter, Charles-Clemens Rüling, « Le management des opérations », dans : *Management. L'essentiel des concepts et pratiques*, Pearson, 2014, p. 507-539.
- Management Industriel et Logistique : Concevoir et piloter la Supply Chain, Baglin et al.

Resources

Teaching staff: professors from CentraleSupélec expert in operations management and industrial stakeholders

Learning outcomes covered on the course

- Understand the challenges and issues related to the design, monitoring and management of production and distribution systems for goods and services
- Know how to identify the different dimensions to integrate: health, safety, finance, environment, social and human
- Understand the articulation of the decisions and the processes which enable to design, control and optimize the performance of a production and distribution system

Description of the skills acquired at the end of the course

In particular, the course will develop the following skills:

C1- Analyse, design and build complex systems with scientific, technological, human and economic components
C2- Develop in-depth skills in an engineering field and in a family of professions
C5- Evolve and act in an international, intercultural and diverse environment
C9- Think and act as an ethical, responsible and honest engineer, taking into account the environmental, social and societal dimensions.

3GS1050 – Technico-economic modeling

Instructors : **Yannick PEREZ**
Department : **DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

The objective of this module is twofold: first, the different technical-economic modeling tools will be presented. Then, these tools will be applied in several practical cases (technical and economic models of the development of electricity transmission networks, costs of deploying 4G terminals, investment choices in different electricity production technologies, level of safety in power plants electrical production…).

Quarter number

SD9

Prerequisites (in terms of CS courses)

No prerequisite

Syllabus

1. Introduction and return to the basics
    a. Measuring value: the price approach
    b. Measuring value: the cost approach
    c. The Impossible Consensus on Measuring Costs: Gravity and the Metric System
    d. Panorama of techno-economic models: which quadrature of the circle?
2. Technical and economic modeling of transport networks
    a. The economic problem: the exercise of the forecast balance of the Electric Transport Network (RTE) aims to forecast the needs of the electricity network in France in 2035-2050 to finance it effectively
    b. The logic behind the construction of scenarios to plan and prepare for the future
    c. What avenues for improving the model used and what limits?
3. Technical and economic modeling of investments in electricity production
    a.The economic problem: in which electricity production technology should companies invest?
    b. Technical parameters: investment volumes, production, availability, etc.
    c. Economic parameters: discount rate, share of own financing, risk of signature, market uncertainty, etc.
    d. Risk sensitivity and decision making
4. Technical and economic modeling of mobile telephony infrastructures
    a. The economic problem: who of the operators or of the State to carry out the investments? What substitution effects - the creation of white areas and what constraint of public service? How are the costs taken into account in this situation?
    b. Refund at the cost declared by the operators or incentive contract?

Class components (lecture, labs, etc.)

Lectures and case studies

Grading

Final written exam (45 min) consisting of the analysis of an industrial project to be developed based on the notions examined during the module

Course support, bibliography

1. ARCEP (2017) les enjeux de la 5G : https://www.arcep.fr/uploads/tx_gspublication/rapport-enjeux-5G_mars2017.pdf

2. MIT (2003), The future of Nuclear Power. http://energy.mit.edu/research/future-nuclear-power/

3. MIT (2007), The future of Coal Power. http://web.mit.edu/coal/

4. MIT (2011), The future of Natural Gas power. https://energy.mit.edu/wp-content/uploads/2011/06/MITEI-The-Future-of-Natural-Gas.pdf

5. MIT (2012), The Future of Electrical Grid. http://energy.mit.edu/publication/future-electric-grid/

6. RTE (2017), Bilan prévisionnel de l'équilibre offre demande d'électricité en France. https://www.rte-france.com/sites/default/files/bp2017_complet_vf.pdf

7. Worldbank (1998), Handbook on Economic analysis of Investment decision http://siteresources.worldbank.org/INTCDD/Resources/HandbookEA.pdf

8. Worldbank (2006), Handbook for evaluating infrastructure regulation http://siteresources.worldbank.org/EXTENERGY/Resources/336805-1156971270190/HandbookForEvaluatingInfrastructureRegulation062706.pdf

Resources

Teaching staff: Yannick Perez, Vincent Rious

Learning outcomes covered on the course

At the end of this module, the student will be able to:

1. Perform an economic calculation and understand the main assumptions

2. Analyze investment projects and determine their validity conditions

Description of the skills acquired at the end of the course

Validated skills:
C1
C9

3GS1060 – End-of-sequence project

Instructors : **PIERRE ALEXANDRE PHELIPOT, Marija JANKOVIC, Evren SAHIN, François CLUZEL, Guillaume Sandou**
Department : **DOMINANTE - GRANDS SYSTÈMES EN INTERACTION**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The objective of this project at the end of the SD9 teaching period is to anchor the knowledge discussed in mandatory classes and to permit students to experience real-life challenges addressing complex system design. With regard to industrial challenges and in relation to the perimeter of the major GSI, the students will be required to propose scenarios or solutions in order to address requirements defined for the design of different systems: control systems, technological systems or operational systems. In view of investigation of this imposed concrete subject, the students will be in a position to implement methods and approaches that were previously discussed during classes.

Quarter number

SD9

Prerequisites (in terms of CS courses)

No prerequisite

Syllabus

Students will be asked to choose one of the three projects proposed that are defined with regard to the teaching objectives of 3rd year concentrations. The choices are not conditioned by their choice of the concentrations. The objective is to allow students to explore working of various types of systems yielding in the development of a transversal understanding of complex system design.

Project steps will be the following:
-Project requirements presentation as well as required deliverables,
-Autonomous teamwork with the support of the teaching staff,
-Results presentation and discussion in front of the expert-based jury.

Class components (lecture, labs, etc.)

Project based methodology

Grading

Project based report and defense in front of the jury.

Course support, bibliography

NA

Description of the skills acquired at the end of the course

C1 - Analyze, design, and build complex systems with scientific, technological, human, and economic components
C4 - Have a sense of valude creation for his company and customers
C7 - Know how to convince
C8 - Lead a project, a team

3GS2010 – Control of nonlinear systems

Instructors : **Pedro Rodriguez-Ayerbe**
Department : **MENTION CONTROL ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **85**
On-site hours (HPE) : **51,00**

Description

The objective of this course is to present the methods and concepts for analyzing a specification for the control of a dynamic system, to design a control law for a complex system based on a nominal non-linear dynamic model, and to implement a control law based in particular on optimization algorithms. In particular, this course discusses and compares different approaches to control law determination based either directly on the non-linear model or on a linear approximation: optimal control (dynamic programming, Pontryagin principle, Linear Quadratic / LTR control), predictive control and sliding mode control.

Quarter number

SG10

Prerequisites (in terms of CS courses)

- SG1 : Convergence, Integration, Probability, Partial differential equations
- ST2 : Modeling
- ST4 : Signal processing
- ST5 : Control theory
- SD9 : Control of complex systems

Syllabus

Part 1: Linear Quadratic Gaussian (LQG) control (CM: 6h, TD 3h, TP 3h)
This first introductory part deals with linear quadratic control based on a linear state representation. The control law is obtained by minimising a quadratic criterion which considers a compromise between the desired performance and the control effort. If required, the control law can be completed by synthesising an observer. The synthesis and analysis tools studied in this section are necessary before tackling non-linear control techniques.

- Linear Quadratic (LQ) control
- Case of measurable disturbances and their rejection
- LQ control with integral action
- State feedback control with observer
- Kalman filter (duality with LQ control)
- Linear Quadratic Gaussian (LQG) control
- Separation theorem
- Performance and robustness analysis of a control law
- Definition of stability margins in the multivariable case.
- Special case of stability margins in the monovariable case
- Special case of LQ and LQG laws - Loop Transfer Recovery (LTR effect)

Part 2: Non-linear control (CM: 4.5h, TD 3h, TP3h)
This part first deals with the analysis of the stability of non-linear systems by the first and second Lyapunov method, i.e., by linearization and through Lyapunov functions. It also introduces the study of trajectories around equilibrium points in the phase plane for second-order systems. Then the link between linearity and non-linearity is studied, with in particular the feedback linearization of non-linear systems. Finally, a control with a variable structure is presented: the sliding mode control. This technique will be studied for control law synthesis and observer synthesis.

Part 3: Optimal control (CM: 6h, TD 3h, TP 3h)
The aim of this part is to present and apply methods for calculating optimal control laws from a state space model. First, the main results related to the optimal control of a non-linear system are presented via dynamic programming. The Pontryagin maximum principle defining the conditions of optimality is presented and numerical

methods for the resolution of the optimal control are treated: the resolution of the problem at both ends by shooting methods and the study of singular arcs. Then the special case of the LQ control, corresponding to the quadratic optimal control for linear systems, is discussed. Finally, it presents open-loop control and trajectory generation.

- Dynamic Programming
- Pontryagin Maximum Principle
  - Solving the problem at both ends by shooting methods
  - Study of singular arcs
- Open-loop control and trajectory generation

Part 4: Predictive control (CM: 4.5h, TD 3h, TP 3h)
The "predictive control" section aims to present the basic ideas of the predictive strategy. In the general non-linear case under constraints, the optimization methods under constraints allowing the elaboration of the control law are more specifically analyzed in terms of feasibility and real time computation load. In the particular case of linear without constraint, leading to the elaboration of the controller in an equivalent RST form, two methods (GPC and PFC) are more specifically developed and compared, under the aspect of performance and choice of control parameters. Extensions to a cascade structure are envisaged.

- Anticipatory aspect
- Constraints
- Optimality

Industrial intervention (4.5h)

Class components (lecture, labs, etc.)

This course is made of 30 hours of lectures (CM), tutorial (TD) and practical work (TP).

Grading

The final grade is calculated from the evaluation of the reports of the work done in the 4 TP. The mark takes into account the preparation, analysis and experimental results of the 3 hour practical sessions.

Course support, bibliography

- H. K. Khalil, "Nonlinear systems" (3rd ed), Prentice Hall, 2002.
- V. Utkim, J. Guldrer et J. Shi, "Sliding Mode Control in Electromechanical Systèms", Deuxième édition, CRC Press, 2009.
- P. Boucher, D. Dumur, “La commande prédictive”, Collection Méthodes et pratiques de l’ingénieur, Editions Technip, Paris, 1996.
- J. M. Maciejowski, “Predictive control with constraints”, Ed. Prentice Hall, Pearson Education Limited, Harlow, 2002.
- B. D. O. Anderson and J. B. Moore, Optimal Control - Linear Quadratic Methods, Prentice Hall, 1989.
- Bryson, A. E., Ho, Y. C., "Applied optimal control: optimization, estimation and control". CRC Press, 1975.

Resources

The teaching team is made of:
Mr Didier Dumur - Predictive Control (Course/TD) - Automatic Control Department
Ms Sihem Tebbani - Optimal Control (Lectures/TD/TP) - Mechanics and Energy Processes Department
Mr Pedro Rodriguez-Ayerbe - Non-linear control (Lectures/TD/TP) - Predictive control (TD/TP) - Optimal control (TP) - Automation Control Department
Dedicated laboratory room in the Eiffel building.

Learning outcomes covered on the course

At the end of this course, the student will be able to analyze a specification concerning the control of a dynamic system. From a possibly non-linear model of the dynamic system they will also be able to choose the synthesis model, linearized around an operating point or non-linear, and the most appropriate control method to check the specifications. They will finally be able to synthesize the control law and analyze the performance and robustness characteristics obtained with this control.

Description of the skills acquired at the end of the course

This course offers an opportunity to deepen skills C1.2, C1.3, C1.4, C2.1 and C2.2.
- Design a control law from a nominal dynamic model
- Analyzing a set of specifications concerning the control of a dynamic system
- Implementing an optimization-based control law

3GS2020 – Hybrid system modelling and control

Instructors : **Giorgio Valmorbida**
Department : **MENTION CONTROL ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

Several complex systems such as transportation systems, communication, energy, and water distribution networks, and industrial and biological process are fundamental to our society. In these systems, continuous-time dynamics are controlled or supervised by computer-embedded discrete-time dynamics and their performance, as well as their safety requirements, must be assessed with tools that account for the interplay of these two types of dynamics.

Hybrid Dynamical Systems are studied by a theoretical framework that allows to simultaneously account for event-based and continuous-time dynamics, therefore enabling efficient design and analysis.

The goal of this course is to introduce the control engineer to the specific phenomena, models, and methods to study Hybrid Dynamical Systems, as well as to present the main computational tools used in its analysis. Examples motivated by applications will illustrate the studied theoretical aspects.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Courses of term 9 (séquence 9) Grand Systèmes en Interaction

Syllabus

The course is composed of two parts of 6 hours each. The definitions and main results will be illustrated by practical engineering examples (Autonomous Vehicles, Power Electronics)

Part 1 : Modelling and simulation (3h course - 3h tutorials)
Mathematical modeling of hybrid systems. The presented topics are:

- Characterisation of Hybrid Systems
- Hybrid Automata
- Switching systems
- Piece-wise affine systems
- Hybrid simulation

Part 2 : Analysis and Control (3h course - 3h tutorials)
Analysis and control design for Hybrid Systems

- Well-posed systems, Zeno Phenomena
- Stability
- Dwell-time
- Stabilizing control laws

Class components (lecture, labs, etc.)

Cours in a classroom with slides and white/blackboard. Tutorial on computers.

Grading

The evaluation will consist of a list of exercise and two report of tutorial classes
List of exercises (40%), Tutorials reports (60%)

Course support, bibliography

Switching in Systems and Control. Daniel Liberzon. Birkhauser, 2003

Resources

- Professors : Giorgio VALMORBIDA
- Tutorials : Control Engineering cohort.
- Software : Simulink Stateflow de Matlab, Semi-Definite Programming tools (Yalmip, SeDuMi, Mosek)
- Rooms for tutorials : Classrooms to be displayed in the course calendar.

Learning outcomes covered on the course

At the end of the course, the student will be able to

- Identify a behavior related to a Hybrid System,
- Model different hybrid systems and simulate them,
- Study its behavior, in particular, its stability via sufficient stability conditions,
- Design a stabilizing hybrid control law

Description of the skills acquired at the end of the course

The main skill to be developed are

C1.2 : Use and develop suitable models and its simplifying assumptions to dress the problem.

C2.2 : Acquire a thorough understanding of a engineering science topic.

3GS2030 – Global analysis of nonlinear dynamical systems.

Instructors : **Antoine Chaillet**
Department : **MENTION CONTROL ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Among the sources of a system's complexity are the nonlinearity of the equations that rule it and the interaction between its multiple constituents. The 1A Modeling course and the 2A Control Engineering course, as well as several courses of the 3A mention Control Engineering, allow to model, identify, control and assess robustness of a system around a given operating point. The objective of this course is to present tools to analyze the global behavior of a system: not only around an operating point, but by taking into account its full dynamics, including its possible nonlinearities. Such an approach allows not only to ensure that the nonlinearities do not compromise the theoretical predictions made on the linearized model (or at least to determine their domain of validity), but also to study systems evolving on a limit cycle. This course focusses on analysis techniques and do not cover specific control design.

Quarter number

SG10

Prerequisites (in terms of CS courses)

- ST2 : Modeling
- ST4 : Signal processing
- ST5 : Control theory
- All courses of 3A mention « Control engineering ».

Syllabus

Chapter 1 : Specific problems posed by nonlinear systems (CM : 1.5h)
This first chapter introduces the specific difficulties posed by the analysis of systems whose dynamics is nonlinear. It underlines in particular the possible lack of robustness with respect to external disturbances, despite a good internal stability. It also points towards problems linked to the interconnection of nonlinear systems, by showing that the cascade interconnection of such systems may induce instability (which is not the case for linear systems). It finally outlines the complexity of solutions that can be generated by a nonlinear plant, such that the existence of limit cycles or chaotic behaviors.

Chapter 2 : Tools for the analysis of autonomous systems (CM : 6h, TD: 1.5h)
The second chapter briefly recalls stability analysis techniques through linearization and proposes, using Lyapunov functions, a method to estimate the domain of attraction of a stable equilibrium. It also deepens stability analysis with LaSalle's invariance principle. It then introduces the phase- plane representation of bidimensional systems as well as the notion of limit cycle. It finally presents the cycle criterion and the describing function method, that allow in particular to study stability of linear systems in feedback with a nonlinear device.

Chapter 3 : Tools for the analysis of perturbed systems (CM : 4.5h)
This chapter introduces the concept of input-to-state stability, which guarantees a certain robustness to the system with respect to external disturbances, as well as tools to establish this property in practice.

Chapter 4: Tools for the analysis of interconnected systems (CM : 3h)
This last chapter uses the input-to-state stability property to study the stability of interconnected systems. It focuses in particular on the cascade and feedback interconnections.

Class components (lecture, labs, etc.)

The course is made of lectures and exercise sessions.

Grading

The evaluation is made through a final written exam (1.5h).

Course support, bibliography

- Nonlinear systems, by Hassan K. Khalil, Prentice Hall, 2002
- Nonlinear Dynamics and Chaos, with applications to physics, biology, chemistry, and engineering, by Steven Strogatz, CRC Press, 2015
- Régulation Industrielle, Chapitre 17 : Analyse des systèmes non linéaires, by E. Godoy et coll., 3ème Ed., Dunod, 2019

Resources

The teaching team is made of two professors from the Automatic Control department.

Learning outcomes covered on the course

By the end of this course, students will be able to analyze a system globally (meaning without restricting the analysis to a neighborhood of the operating point) and to guarantee its robustness to external disturbances, parameter uncertainties, or neglected dynamics. They will also be able to analyze systems that do not converge to an operating point, but rather periodically evolve along a limit cycle. They will finally be able to predict whether the interconnection of stable subsystems does not compromise the stability of the overall system.

Description of the skills acquired at the end of the course

This course offers an opportunity to deepen skills C1.2, C1.3, C1.4, C2.1 and C2.2.

3GS2040 – Control architectures of complex systems

Instructors : **Cristina-Nicoleta Maniu**
Department : **MENTION CONTROL ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

When systems are composed by numerous components for which it is interesting to maintain a certain degree of autonomy or confidentiality (e.g. Smart Grid, Industrie 4.0) or when their structure evolves dynamically (e.g. swarm of UAVs, intelligent highway), it is important to structure the control system such that it can adapt while guaranteeing the expected level of performance. The objective of this teaching module is to propose decentralized/distributed/hierarchical/consensus-based control techniques together with the conditions to achieve the performance level of centralized control taught in other courses, while keeping a reasonable computation load.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Control Theory course (2nd year)

Syllabus

Part 1: Modeling and control of complex systems (3h CM & 3h TD)
- Modeling of complex systems
- Centralized/decentralized/distributed predictive control

Part 2: Consensus-based control (3h CM & 3h TD)
- Communication graph
- Consensus-based control
- Application to formation control of multi-vehicle systems

Part 3: Case study (6h)
- Scenario, state-of-the-art, simulations, experimentations (working in small tutored groups)

Part 4: Interactive posters session (3h)
- See, for instance, the interactive posters session in 2022
https://twitter.com/centralesupelec/status/1513506223416651781?s=20&t=OkQQpLLgULxJ4TNN56_YnQ

Class components (lecture, labs, etc.)

- Interactive courses
- Matlab-based tutorials
- Case study
- Experimentations on multi-vehicle systems
- Working in small tutored groups
- Peer assessment

Experiments on mobile robots are envisaged (funding via the projects: 1.*MEECOD – Moderniser l'Enseignement par l'Expérimentation sur la Coordination de Drones,* with the support of UPSaclay on *Initiatives Pédagogiques – Oser !* ; 2. *DAReTeach – Drone Arenas-based Remote International Teaching, with the support of the FACE*

Foundation – French-Américan Cultural Exchange in Education and the Arts ; 3. (*Re)CreativeRobot – (Re)Creative Mobile Robotics for Kids*, with the support of the *International Federation of Automatic Control Foundation*).

Grading

The final grade is computed from the report evaluation (50%) and the interactive poster assesment, both design and presentation (50%).
A skill-based assement is also envisaged. The skills C1, C7 and C8 will be assessed.

Course support, bibliography

- I. Alvarado, D. Limon, D. Muñoz De La Peña, J.M. Maestre, M.A. Ridao, H. Scheu, W. Marquardt, R.R. Negenborn, B. De Schutter, F. Valencia, J. Espinosa, “A comparative analysis of distributed MPC techniques applied to the HD-MPC four-tank benchmark”, *Journal of Process Control*, 21 (5), 800-815, 2011.
- V. Baillard, A. Goy, N. Vasselin, C. Stoica Maniu, “Potential field based optimization of a prey-predator multi-agent system”, *Preprints of the 9th Vienna International Conference on Mathematical Modelling*, Vienna, Austria, pp. 725-726, February 21-23, 2018.
- L. Bakule, “Decentralized control: An overview”, *Annual Reviews in Control*, 32, pp. 87–98, 2008.
- T. Chevet, C. Vlad, C. Stoica Maniu, Y. Zhang, “Model Predictive Control techniques for UAVs formation deployment and reconfiguration”, *Journal of Intelligent & Robotic Systems*, Springer, Special Issue on “Unmanned Aerial Systems”, pp. 1-16, 2019.
- G. Cohen, “Optimisation des grands systèmes”, *handout CERMICS-Ecole Nationale des Ponts et Chaussées et INRIA*, 2004.
- A. J. Conejo, E. Castillo, R. Mínguez, R. García-Bertrand, “Decomposition Techniques in Mathematical Programming”, *Engineering and Science Applications*, Springer, 2006.
- M. Farina, G. Ferrari Trecate, “Decentralized and distributed control”, *EECI-HYCON2 Graduate School on Control*, Gif-sur-Yvette, 2015.
- F. Fele, J.M. Maestre, E.F. Camacho, “Coalitional control: Cooperative game theory and control, *IEEE Control Systems Magazine*, 37 (1), 53-69, 2014.
- J. Lunze, “Feedback control of large scale systems”, Upper Saddle River, NJ, USA: *Prentice Hall, Systems and Control Engineering*, 1992.
- J. M. Maestre, R. Negenborn, “Distributed Model Predictive Control Made Easy”, *Springe*r, 2014.
- M.T. Nguyen, “Commande prédictive sous contraintes de sécurité pour des systèmes dynamiques Multi-Agents”, *PhD thesis*, Université Paris-Saclay, 2016.
- K.K. Oh, M.C. Park, H.S. Ahn, “A survey of multi-agent formation control”, *Automatica*, vol. 53, pp. 424-440, 2015.
- I. Prodan, “Commande des systèmes dynamiques Multi-Agents en présence de contraintes”, *PhD thesis*, Supélec, 2012.
- J.B. Rawlings, D. Q. Mayne, “Model predictive control: theory and design”, *Nob Hill Pub*., Madison, WI, USA, 2009.
- Y. Rochefort, H. Piet-Lahanier, S. Bertrand, D. Beauvois, D. Dumur, “Model predictive control of cooperative vehicles using systematic search approach”, *Control Engineering Practice*, vol. 32, pp. 204-217, 2014.
- D.D. Siljak, “Decentralized control of complex systems”, *Mathematics in Science and engineering*, vol. 184, Academic Press, 1991.
- S. Wilson, P. Glotfelter, L. Wang, S. Mayya, G. Notomista, M. Mote, M. Egerstedt, “The Robotarium: Globally Impactful Opportunities, Challenges, and Lessons Learned in Remote-Access”, Distributed Control of Multirobot Systems, *IEEE Control Systems Magazine*, 40(1), 26-44, 2020.
- A. Zafra-Cabeza, J.M. Maestre, M.A. Ridao, E.F. Camacho, L. Sánchez, “A hierarchical distributed model predictive control approach to irrigation canals: A risk mitigation perspective”, *Journal of Process Control*, 21 (5), 787-799, 2011.

Resources

Teaching staff: Cristina Stoica, Cristina Vlad, Sylvain Bertrand (ONERA)

Experimentations on mobile robots in the indoor flight arena of CentraleSupélec are envisaged.

Learning outcomes covered on the course

After completion of this course, students will be able to:
1. Describe and recognize the behavior of a complex system (large scale system, multi-agent system, etc.) by carring out a state-of-the-art on the subject;
2. Model and structure a complex system (large scale system, multi-agent system, etc.) by proposing an appropriate dynamic representation;
3. Analyze time-domain/frequency specifications and propose a control law structure for a complex system (large scale system, multi-agent system, etc.) based on the considered model;
4. Identify the limits of a centralized control law of a complex system (large scale system, multi-agent system, etc.) by analyzing the behavior of the closed-loop system with respect to the specifications;
5. Synthesize a decentralized/distributed/hierarchical/consensus-based control law for a complex system (large scale system, multi-agent system, etc.) and validate it in simulation;
6. Validate the proposed control law on an experimental multi-vehicle testbed.

Description of the skills acquired at the end of the course

C1.1 – Analyze: study a system as a whole, the situation as a whole. Identify, formulate and analyze a system within the framework of a transdisciplinary approach with its scientific, economic, human dimensions, etc.
C1.2 – Modeling: using and developing the appropriate models, choosing the right modeling scale and the relevant simplifying assumptions
C1.4 – Design: specify, implement and validate all or part of a complex system
C2.3 – Identify and independently acquire new knowledge and skills
C5.3 – Analyze global and / or local issues internationally and adapt projects or solutions to them
C7.1 – Know how to convince basically: Structure your ideas and arguments, be synthetic (assumptions, objectives, expected results, approach and value created)
C7.3 – Know how to convince about yourself: Being comfortable and being convinced, showing empathy and managing your emotions
C8.1 – Build the collective to work as a team
C8.2 – Mobilize and train a collective by showing leadership

3GS2050 – System Modelling, identification and analysis

Instructors : **Guillaume Sandou**
Department : **MENTION CONTROL ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **65**
On-site hours (HPE) : **39,00**

Description

The modelling of a system and the determination of numerical values for the model is a crucial first step in the control of complex systems. It allows, among several objectives, to analyze the structural properties of a system. This module aims to tackle at first the methods allowing to represent a system and to analyze the properties of stability, controllability and observability in the framework of multivariable systems. Thecase of nonlinear systems is also presented. The identification methods are then presented (prediction error methods), having a deep interest in the experience choice and design.
The general objective of this module is to provide students with the concepts, tools and methodologies to model and represent a system, to identify the numerical values for the possibly few models obtained, to analyze their structural properties (stability, poles, controllability....) and to simulate them in a multi-physics framework.

Quarter number

SG10

Prerequisites (in terms of CS courses)

CentraleSupélec modules :

- Modelling : model representations and analysis (ST2)
- Control Theory (ST5)

General prerequisites :

- Matrix computation, basis of numerical integration of differential equations

Syllabus

A. System representations and analysis, systems structure, model order reduction : 24 on-site hours (15h lectures + 9h tutorials)
This first part deepens some notions that have been introduced in the Control Theory module in ST5, giving some supplements especially in the framework of multivariable systems. The concepts linked to system norms and order reduction are also presented.

-Supplements on state-space representation for linear systems (7,5h lectures + 1,5h Tutorial + 1,5h synthesis tutorial)
Controllability, observability, Gramians, minimal representation, multivariable poles and zeros

-System norms (1,5h lecture)
H2, Hinfini and Hankel norms

-Nonlinear systems analyzis (4,5h lecture, 3h Tutorial)
Lyapunov functions, stability theorem, controllability and observability for nonlinear systems, feedback based linearization

- Order reduction (1,5h lecture, 3h tutorial)
Singular value decomposition, Proper and orthogonal decomposition (POD), balanced gramians method

B. System Identification: 13,5 on-site hours (7,5h lecture + 3h tutorials + 3h lab-work)
This third part presents the methods that aim to determine the numerical values of a system model. The methodology given here tries to go beyond the algorithms only to insist on the importance of the model choice and the experiment design. The main focus is given on models that are expressed by means of discrete-time transfer functions.

-Generalities on the identification of a linear system
Generalities object/model. Candidate models: output error models, equation error models (AR, MA, ARMA... ARX, ARMAX, OE...). Experimental process: choice of a signal for the analyzis, use of Pseudo Random Binary Sequence, experiment precaution, data preprocessing.

-Non parametric identification of a linear model
Correlation based identification. Application to the determination of an impulse response with the help of a Pseudo Random Binary Sequence.
Frequency analyzis: use of Fourier transform, estimation of the power spectral density. Influence of the feedback.

-Parametric identification of a linear model
Principles. Distance object/model. Prediction error based method (Infinite past prediction, principle). Case of ARX, ARMAX models.
General case: prediction error based method, asymptotic analyzis, iterative procedure, evaluation of gradients. Frequency domain interpretation of the minimized criterion.
Linear regression: Least-square methods. Asymptotic analyzis, use of QR decomposition, recursive least-squares. Instrumental variable method. Research and validation of a structure. Residus analyzis. Least-square extensions: extended least squares, generalized least-squares.

-Laboratory work, 3h

Class components (lecture, labs, etc.)

- Lectures and tutorials illustrated by examples taken from real industrial issues.
- Laboratory work to illustrate the identification part.

Grading

- Written exam (1,5h, 2/3 of the module grade) for part A. Documents and calculators allowed.
- Evaluation for part B – Identification from the Laboratory Work report (1/3 of the module grade).
- Skill C1 will be evaluated during the written exam, and skill C6 will be evaluated during the Identification Laboratory Work

Course support, bibliography

- William S. Levine. The Control Handbook. CRC Press. ISBN 9781420073669
- OpenModelica User's Guide, Release v1.16.0
- Lennart Ljung. System Identification: Theory for user. Prentice Hall, Information and system sciences series.
- Torsten Söderström, Peter Stoica. System Identification. Prentice Hall International series in Systems and Control Engineering.

Resources

- Pedagogical team : Guillaume SANDOU, Stéphane FONT
- Software : Matlab
- Tutorials and laboratory works in the dedicated rooms in the Control Department (10 workstations)

Learning outcomes covered on the course

At the end of this module, students will be able to:

- Choose and manipulate the representation of a multivariable system model, eventually with a large dimension
- Analyze the structural properties of a model
- Reduce the model order depending of the final goal of this model
- Propose a representation structure of the experience from the data, with a continuous time or a discrete time model

- Performing the parameter identification of the (discrete-time) transfer functions that is used for the structural representation of the system
- Analyze the relevance of the determined model, in particular by taking into account the identification residus analyzis.

Description of the skills acquired at the end of the course

This module will adress the following skills:

C1.2 Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when adressing a problem
C1.3 Apply problem-solving through approximation, simulation and experimentation
C2.2 Transfer knowledge and methodology across multiple disciplinary fields
C3.2 Question assumptions and givens. vercome failures. Take decisions
C6.1 Identify and use the necessary software for one's work (including collaborative tools) and adpat digital responses according to the context.
C8.1 Work collaboratively in teams.

3GS2210 – Modelling and analysis of uncertain systems

Instructors : **Guillaume Sandou**
Department : **MENTION CONTROL ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

A complex system is always concerned with some uncertainties (misknown parameters, neglected phenomena, disturbances). This module presents some modelling and analyzis methodologies that allow to tackle the case of uncertain systems so as to guarantee some stability and performance properties in face with uncertainties. As a result, this module gives a focus on the robustness analyzis by means of a probabilistic approach (Monte Carlo simulations, uncertainty propagation) and a set membership approach (mu-analyzis).

Quarter number

SG11

Prerequisites (in terms of CS courses)

- Modelling: model representations and analyzis (ST2 module)
- System modelling, identification and analyzis (module SG10 in the Control Engineering concentration)

Syllabus

A. Robustness analyzis with a probabilistic approach (6 on-site hours : 3h lectures + 3h tutorial (Laboratory Work with a report)

This part gives a reminder about some notions that have been briefly introduced in the "Modelling" module in ST2. Some reminders about the sensitivity indexes are presented, and then a particular focus is done on Monte Carlo techniques to investigate for the robustness analysis of a controlled system from a probabilistic point of view.

- Probabilisic uncertainty modelling
- Monte Carlo analyzis
- Sensitivity analyzis, uncertainty propagation

B. Robustness analyzis with a set membership approach, mu-analyzis (10,5 on-site hours: 4,5h lectures + 3h tutorials + 3h Laboratory Work with report)

This part deals with a particulary efficient robustness analyzis method, relying on the Hinfinity norm. The module presents the "standard form" framework to represent a system, and describes firstly the unstructured robustness analyzis (small gain theorem) and secondly the structured one (mu-analyzis).

- Set membership uncertainty representation (interval, ellipsoïd, with the Hinfinity norm)
- Standard form representation
- Unstructured robustness analyzis, small gain theorem
- Mu-analyzis for the robustness analyzis: parameter uncertainty, neglected dynamics
- Introduction to the performance robustness analyzis

C. Industrial conference (1,5h lecture)

Class components (lecture, labs, etc.)

- Lectures and tutorials illustrated by examples taken from real industrial issues.
- Laboratory work for the implentation of robustness analyzis methods
- Industrial conference

Grading

- Report on the Laboratory Work on Monte Carlo robustness analyzis (50% of the final grade)
- Report on the Laboratory Work on mu-analyzis (50% of the final grade)
- Skills C1 and C6 will be evaluated during the Laboratory Works

Course support, bibliography

- Gilles Duc, Stéphane Font, Commande H infini et mu-analyse. Hermès.
- Kemin Zhou, John C. Doyle, Keith Glover, Robust and optimal control. Prentice Hall, 1996, ISBN 0134565673, 9780134565675
- Johnathan Mun, Modeling risk, third edition: applying Monte Carlo Risk simulation, strategic real options, stochastic forecasting, and portfolio optimization. Wiley

Resources

- Pedagogical team : Guillaume SANDOU, Stéphane FONT
- Software : Matlab
- Tutorials and laboratory works in the dedicated rooms in the Control Department (10 workstations)

Learning outcomes covered on the course

At the end of the module, students will be able to:

- model and represent the uncertainties with a probabilistic or set membership approach
- analyze and guarantee the stability properties of a controlled system in face with uncertainties
- numerically implement the robustness analyzis methods

Description of the skills acquired at the end of the course

This module will adress the following skills:

- C1.2 Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when adressing a problem
- C1.4 Design, detail and corroborate a whole or part of a complex system
- C6.5 Operate all types of data, structured or unstructured, including big data
- C8.1 Work collaboratively in teams.

3GS2220 – Control of uncertain systems

Instructors : **Maria Makarova**
Department : **MENTION CONTROL ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course deals with the control of systems by methodological tools relying on more advanced theoretical concepts than those introduced in the 2nd year Automatic control course and in period 9 of the GSI dominant. It covers the case of systems in presence of uncertainties, and deals with the topics of robustness and observation in a stochastic context.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Courses from period 9 (GSI) et 10 (Control Engineering)

Syllabus

-Hinfini control (2 lectures x 1.5 HPE; 2 tutorials x 1.5 HPE)
- Notion of standard problem, solution by Riccati equations, by LMI
- Performance and robustness are taken into account by introducing frequency weightings.

-Control of linear parameter-varying systems (2 lectures x 1.5 HPE; 1 tutorial x 1.5 HPE)
- Introduction to LPV systems
- Stability and performance analysis: polytopic systems, LFT systems
- Controller design: polytopic systems, LFT systems

-Advanced estimators (3 lectures x 1.5 HPE; 2 tutorials x 1.5 HPE)
- Reminders: Kalman continuous time filter, asymptotic filter in the context of state space control
- Discrete-time Kalman filter, Kalman filter extensions (variants)
- Non-linear context: extended Kalman filter (EKF), unscented filter (UKF)

-Industrial case study
- 1 BE x 3 HPE

The concepts seen in this course will be applied during a 3-hour practical session in the "Experimental Implementation" module.

Class components (lecture, labs, etc.)

Lectures will be complemented with computer-based tutorial sessions (in groups of two or three) to apply the theoretical concepts on practical case studies. The tutorials will require preparatory personal work outside class.

Experimental implementation of the concepts seen in the course (module "Experimental implementation").

Grading

The learning outcomes will be assessed on the basis of the work carried out in the 3-hour laboratory "Experimental implementation" (evaluation of the work carried out in preparation and during the session, and of the report).

Course support, bibliography

Y. Bar-Shalom, X.-Rong Li, Thiagalingam Kirubarajan, Estimation with Applications to Tracking and Navigation: Theory, Algorithms and Software, Wiley 2002

R. G. Brown, P. Hwang, Introduction to random signals and applied Kalman filtering. Wiley, 1997

Jean-Marc Biannic, Variations autour de la commande LPV, cours ISAE : http://jm.biannic.free.fr/PDF/coursISAE_LPV.pdf, 2014.

G. Scorletti, V. Fromion. Automatique Fréquentielle Avancée, polycopié Centrale Lyon, : http://cel.archives-ouvertes.fr/docs/00/42/38/48/PDF/cours_Hinf_Lyon.pdf, 2009.

O. Sename, P. Gaspar, J. Bokor (Eds.), Robust Control and Linear Parameter Varying Approaches – Application to Vehicle Dynamics, Springer, 2013.

S. Skogestad, I Postlethwaite, Multivariable feedback control – Analysis and design (2nd edition). John Wiley and Sons, 2005.

K. Zhou, J.C. Doyle, K. Glover, Robust and Optimal Control. Prentice Hall, 1996.

Resources

Teaching staff (instructor(s) names):

- Hinfinity control methods: Stéphane Font
- Control of linear parameter-varying systems : Cristina Stoica
- Advanced estimators: Maria Makarov
- Industrial case study : Philippe Feyel (Safran)

Maximum enrollment: tutorial groups of max 15 students
Software, number of licenses required: Matlab (with Control and Robust control toolboxes), campus license
Lab classrooms : classrooms of Automatic control department

Learning outcomes covered on the course

At the end of this course, the student will be able to implement estimation methods in various situations and in particular for non-linear and/or uncertain systems, and to design robust controllers for linear, and linear with varying parameters systems (or non-linear systems treated as such).

Description of the skills acquired at the end of the course

This course is an opportunity for students to deepen their skills C1.2, C1.3, C1.4, C2.1 and C2.2.

- Design and implement a control law taking into account the uncertainties of the model or varying parameters
- Design estimators in the context of non-linear and/or uncertain systems.

Evaluated skill at the end of the course: C1 milestone 3

3GS2230 – System reliability and predictive maintenace

Instructors : **Anne BARROS**
Department : **MENTION CONTROL ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **32**
On-site hours (HPE) : **19,50**

Description

The security of production systems and infrastructure is a major concern for manufacturers and public authorities. Programmable electronic systems, and in particular control systems, are widely involved in risk reduction processes and can even be considered as critical. Hence, a standard has been created by the International Electrotechnical Commission (standard IEC61508) dealing with the functional safety of electrical / electronic / programmable electronic systems (E / E / EP) relating to safety. Many industries such as railway, nuclear industry, automotive industry, oil and gas production, petrochemical and chemical production, the manufacturing sector use different Taylor made versions of this standard. The objective is to assess, via quantitative and qualitative analysis tools, the reliability or availability of the command and control systems used to ensure the safety of an installation.

This course first covers the classic concepts and methods of dependability (fault trees, reliability diagrams, Markov chains, Monte Carlo simulation, etc.) commonly used to assess the reliability or availability of control and command systems and to meet the normative requirements in terms of security. Emphasis is then placed on the development of predictive maintenance strategies by integrating the problems of diagnosis and adaptive control that are specific to command and control systems..

Quarter number

SG11

Prerequisites (in terms of CS courses)

Basic knowledge in probability, statistics and Monte Carlo Simulation

Syllabus

1. Dependability, statistical models, machine learning and probabilistic models (3h)
2. Qualitative analysis of systems: functional / dysfunctional analysis, fault trees, reliability diagrams, graphs (3h)
3. Quantitative analysis for the calculation of performance indicators from fault trees and Boolean models: exact and approximate calculations (3h)
4. Quantitative analysis for calculating performance indicators from graphs: Markov chains and Monte Carlo simulation (3h)
5. Application to predictive maintenance I: modeling and forecasting of the degradation of a system. Link with diagnostic and reconfiguration issues (3h)
6. Application to predictive maintenance II: Optimization of maintenance strategies. Link with diagnostic and reconfiguration issues (3h)
7. Use case (6h)

Class components (lecture, labs, etc.)

9h of lectures, 9h of tutorials, and 6h of use case study as an evaluation

Course support, bibliography

Bibliography:

- Isermann, R. (2011). "Fault-Diagnosis Applications: Model-Based Condition Monitoring: Actuators, Drives, Machinery, Plants, Sensors, and Fault-tolerant Systems". Springer Berlin Heidelberg.
- Rausand, M.: "Reliability of Safety-Critical Systems: Theory and Applications," Wiley, Hoboken, NJ ,2014.
- Cocozza Thivent, C. "Processus stochastiques et fiabilité des systèmes", Springer, 1997
- Norme IEC61508
- Rausand, M. Barros, A. and Høyland, A.: "System Reliability Theory: Models, Statistical methods, and Applications" (3rd ed.), Wiley, 2020.

Material:
Compendium, Slides.

Resources

- Teaching Team
    - Lecture: Anne Barros
    - Tutorials: Anne Barros, YIping Fang, Zhiguo Zeng
- Software: Matlab or Python

Learning outcomes covered on the course

The objectives of this course are to give a basic culture on:

- qualitative analysis methods for the dependability of control systems or of industrial systems in which safety instrumented systems are involved (understand their operation and their dysfunction with a high level of abstraction in the design phase and in the operational phase).
- dependability quantitative analysis methods for control systems which make it possible to calculate performance indicators like reliability, availability, in the design phase and in operation. We will focus in particular on statistical approaches and machine learning approaches for estimation problems, probability law calculations and the use of probabilistic models or Monte Carlo type simulation techniques for the evaluation of average quantities.
- the use of the aforementioned methods for the implementation of predictive maintenance policies in the operational phase.

At the end of this course, the student should be able to:
- understand dependability and safety issues during the design or the operation of control systems,
- perform or specify a dependability and safety study in the design or operation phase for a control system,
- understand predictive maintenance and adaptive control issues for command and control systems,
- evaluate the risk incurred by a choice of design or of operation and make decisions under uncertainty.

Description of the skills acquired at the end of the course

Validated skills

- "understand the issues of operational safety in the design and use phase" as well as "understand the issues of predictive maintenance and adaptive control" are part of C2.1
- "carry out or specify a dependability study", "assess the risk incurred for a choice of design or use of control systems" are part of C2.2 and C2.3
- the evaluation mode is included in C2.4 and C8.1

3GS2240 – Diagnosis and reconfiguration

Instructors : **Sorin Olaru**
Department : **MENTION CONTROL ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **37**
On-site hours (HPE) : **22,50**

Description

The "Diagnosis and Reconfiguration" course is the second part of the "Supervision of complex systems" module and follows the course dedicated to "Dependability".

Quarter number

SG11

Prerequisites (in terms of CS courses)

- ST2 : Modelling
- ST4 : Traitement du signal
- ST5 : Control Theory

Syllabus

Part I: Data-based diagnosis: Statistical tests
Part II: Data-based diagnosis: Supervised learning: regression model and classification, decision trees, neural networks, k-nn.
Part III: Principles of model-based diagnosis. Fault modeling, fault characterization. Fault detection and isolation.
Part IV: Residue generation, residue evaluation, and diagnosis. Robustness issues. Application to residual generation for LTI systems.
Part V: The set-theoretic approach for fault estimation and isolation based on set separation. Residue generation and set characterization via invariant sets.
Part VI: (Unknown input) Observers as a diagnostic tool. Application of diagnostics to feedback control loop reconfiguration. Fault-tolerant control.

Class components (lecture, labs, etc.)

The course corresponds to an hourly volume of 18 hours and will be built on a lecture + tutorial structure (9 hours of lectures and 9 hours of tutorials). The tutorials will be based on numerous case studies from the world of industry.

Grading

Two case-studies of 3h will be organized for each of the modules ("Dependability" and "Diagnosis and Reconfiguration") and will be evaluated separately towards the validation of the competences C1 and will contribute up to 1/3 of the final grade. The remaining 2/3 will be evaluated through a final written exam.

Course support, bibliography

Blanke, M., Kinnaert, M., Lunze, J., Staroswiecki, M., & Schröder, J. (2006). *Diagnosis and fault-tolerant control* (Vol. 2). Berlin: springer.
Varga, A. (2017). Solving fault diagnosis problems. *Studies in Systems, Decision and Control, 1st ed.; Springer International Publishing: Berlin, Germany*.
Stoican, F., & Olaru, S. (2013). *Set-theoretic fault-tolerant control in multisensor systems*. John Wiley & Sons.

Resources

Teaching team (names of the teachers of the lectures) :

- Ms. Anne Barros
- M. Sorin Olaru

TD size (default 35 students): 35 students

Software tools and number of licenses required: Matlab/Simulink, 18 licenses

Learning outcomes covered on the course

The objective of this course is to address the issues of fault (or failure) detection and reconfiguration to compensate for performance losses and ensure safety. Knowing how to detect a faulty behavior of the system or one of its components (sensor, actuator, system sub-component), isolate it and identify it (fault signature) and react accordingly (reconfiguration, switching to a degraded operating mode...) represents a key point of system resilience allowing to limit interruptions of operation or system losses. The state-of-the-art methodologies related to these issues will be presented in the course and the attendees will acquire the capabilities to analyze and design fault-tolerant systems.

Description of the skills acquired at the end of the course

This course is an opportunity for students to deepen their skills C.1.1, C1.2
- Design a diagnosys mechanism starting from the description of a failure scenario and knowing the nominal dynamical model.
- Analyse fault-tolerant control specifications of a dynamical system.
- Implement and adapt diagnosys and reconfiguration methods according to the field of application.

3GS2250 – Robotics and innovation

Instructors : **Maria Makarova**
Department : **MENTION CONTROL ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Using robotics as an example, this course is dedicated to technological innovation with the objective of building collaborative innovation projects.

The following topics are covered:
- requirement specifications and response with a robotic solution,
- emergence and structuring of the system development project,
- impacts (economic, environmental, social and societal dimensions, scientific and technical production, etc.).

From advanced research to implementation in an industrial context, these issues are discussed through the state of the art, challenges and associated perspectives. Practical examples and feedback illustrate the concepts presented.

In addition to a cross-disciplinary view of the construction of innovation projects in robotics, two scientific themes will be discussed in more detail due to their strong current development, namely AI certification and the consideration of human beings within interactive robotic systems.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Courses from period 9 (GSI) and 10 (Control Engineering)

Syllabus

1. Robotics and innovation (lectures 2 x 3h, case study 3h)
2. Certification of intelligent robotic systems (interactive lecture 3h)
3. Human-Robot physical interaction (lecture 3h, case study 3h)

Class components (lecture, labs, etc.)

Series of invited lectures by experts from academia and industry, case studies

Grading

The evaluation will be performed by each teacher through case studies, conducted during class in small groups of students, and resulting in the production of oral presentations and written reports.

Final grade = (grade for case study 1 [Guy Caverot] + grade for case study 2 [Guillaume Bernard] + grade for case study 3 [Pauline Maurice])/3

Course support, bibliography

Resources

Series of invited lectures by experts from academia and industry, case studies

Learning outcomes covered on the course

- Understand and develop the different stages and aspects of a collaborative technological innovation project.
- Understand the complexity of innovative robotic systems, the constraints related to their integration and the associated engineering professions.
- Deepen the understanding of the scientific thematics in current developments

Description of the skills acquired at the end of the course

This course is an opportunity for students to deepen their skills C1, C3, C9

Evaluated skills : C3 and C9

3GS2500 – Control Engineering project

Instructors : **Guillaume Sandou**
Department : **MENTION CONTROL ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

The project of the "Control Engineering" concentration takes place during the whole third year of the curriculum (SD9 - SG10 - SG11) for a total of 240hours (on-site + off-site hours). The goal of this project is to apply the methodologies of complex system modelling, identification and control that are the core of the Control Engineering concentration curriculum. This project is carried out by groups of 2 or 3 students and can be:

- A project carried out in relation with a company, with a deep supervision of the teaching team of the Control Department, and named as a "Convention d'Etude Industrielle";
- A project carried out in relation with a company, with a stronger autonomy asked required for the students, and named as "projet immersion" ;
- A project carried out with an other academic institution.

Quarter number

SD9, SG10, SG11

Prerequisites (in terms of CS courses)

Module "Control Theory "in ST5 and modules of the Control Engineering concentration

Syllabus

240 on-site + off-site hours to:

- Take charge of the problem, looj for relevant information and data
- Develop some solutions
- Experiment and validate the results
- Organize and attend to work meetings
- Write reports
- Present the results

Class components (lecture, labs, etc.)

Project (240 on-site and off-site hours)

Grading

- Mid-term report and presentation (25% of the final grade)
- Final report and presentation (75% of the final grade)

Course support, bibliography

Depend on the projects to be proposed

Resources

Depending of the type of project and the industrial partner:

- Supervision and expertness of the teaching team in the Control Department;
- Softawares and prototypes available in the Control Department;
- Scientific literature databases in CentraleSupélec;
- Data or experimental means available on the partner side.

Learning outcomes covered on the course

A the end of this projet, students will be able to:

- Manage a project over a relatively important duration, respecting milestones and deliverables;
- Apply some methodologies to analyze and control a complex system;
- Provide a critical perspectives on the obtained results;
- Propose innovating and operating solutions in face with industrial issues.

Description of the skills acquired at the end of the course

The project will be the opportunity to deepen part of the following skills:

- C1 Analyze, design and implement complex systems made up of scientific, technological, social and economic dimensions
- C2 Acquire and develop broad skills in a scientific or academic field and applied profesional areas
- C3 Act, angage, innovate within a scientific and technological environment
- C4 Create value for companies and clients
- C7 Strengthen the Art of Persuasion
- C8 Lead a team, manage a project

3GS3010 – R&D and innovation management

Instructors : **Bernard YANNOU**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **50**
On-site hours (HPE) : **30,00**

Description

Managing Research, Development and Innovation activities is the heart of a company. The course provides an overview of knowledge (theories and methodologies) ranging from a company's R&D strategy to the engineering of the development of a value offer (product or service along with its business model) through the definition of market and technology roadmaps, product plans, control of R&D costs and development projects, as well as innovation processes and issues (including innovation protection, skills management, partnership and open innovation strategies).

The objectives are to:

1. **Discover all the stages of the innovative company**: its ecosystem, its strategy, its R&D, its innovation management and its projects for the development of new products / services / business models.

2. **Prepare for innovation and intrapreneurship**, which are recent professions in France and Europe: chief innovation officer, manager-engineer of sustainable innovation, interface roles in the value chain as innovation project manager, open innovation development manager…

3. **Combining both the company's strategy and the theories and methodologies** of innovation management, technology management, development engineering, product design and launch.

Quarter number
SG10

Prerequisites (in terms of CS courses)
No prerequisite

Syllabus

- **Discovering innovation management through play, Bernard Yannou**
  Innovation managers and the consultants they work with have many objectives: to change the way things are done, to develop new managerial practices, to adopt a new organization, to create a culture that is resolutely focused on innovation. But where to start? In what order should actions be taken? Should we act first on the company's ability to generate ideas or on its ability to carry out projects? Should we focus on the commitment of a core group or on the contrary, should we try to involve the whole company? Should you spend months thinking about your strategy or should you make a success of your first project, even if it is not exceptional?
  There are many activities to develop the capacity to innovate in a company and the recent international standard ISO 56002 - Innovation Management System - presents a complete set of them. The Year of Innovation® is a serious game developed to make discover the ISO 56002 and to allow to balance all the facets of the innovating company. Through the practice of the game and the analysis of the game and a conceptualization, you will train and simulate the impact of each action you could implement or advise to improve the innovation capacity of an organization.
- **Managing research and innovation at the national and European levels, Arnault Leservot**
  Why and how should research be managed in France and Europe? Why and how can we ensure that France and Europe are able to compete in key technologies? Why and how can we transfer the value of

this research to markets by trying to promote the creation of industrial champions through the creation of a fabric of deeptech startups?

- **Review of innovation practices and organizational models in large companies - New forms of innovation, Emilie Vallet.** The introduction is based on an assessment of innovative organisation models, the 6 major forces that drive companies to innovate and the forms of innovation that are emerging.
- **Understanding the missions of an innovation director and the interest of open innovation, Stéphane Martinot.** The challenge facing the Director of Innovation is to generate innovations internally, capture innovations from outside the company, and bring them to fruition, all while aligning them within roadmaps that meet market objectives and the company's economic constraints.
- **Driving innovation: Strategy, Upstream Innovation and Execution. Patrick Ternier.** Around the world, the ability to innovate is one of the top 3 priorities for CEOs. Companies are becoming more or less professional in their methods for managing innovation. The aim is to provide an overview of the best practices and underlying technologies used in the US, Europe and Japan, highlighting their respective strengths and weaknesses.
- **Using technology and business roadmaps, Michel Guiga.** How for a company to build, in its competitive environment, its technological roadmap and its market roadmap? Then "cascade" these roadmaps into innovation and development projects.
- **Discovering Radical Innovation Design through play, Bernard Yannou**
Radical Innovation Design® is a disruptive innovation methodology driven by usage invented by B. Yannou at CentraleSupélec. Compatible with classic innovation methods (Design Thinking, CK Theory, Blue Ocean Strategy), it differs from them by providing powerful concepts and a unique structuring process that respond to the pitfalls observed in innovation. These contributions are (i) a systematic structuring (activities, uses, users, key performances and "pain points"), (ii) a segmentation of the problems allowing to define the real need, (iii) an integration of metrics (quantity of pain) and unique concepts (value buckets, perimeter of ambition), (iv) a provision of visualization and decision support tools. The practice of the RID serious game allows to get familiar with these concepts very quickly.
- **Establishing collaborative R&D partnerships, Eléonore Venin.** How can we partner to be stronger? What collaborative R&D strategies? Which strategic alliances? What are the pitfalls and how to avoid them and secure R&D? What role for public funding?
- **Investing and controlling the costs of projects, programs and R&D, Michel Guiga.** What are the financial indicators at the following 3 levels: the R&D of a company, the management of a program or a business line/unit, an innovative project or a development project? How to invest well, control and withdraw in time?
- **Understanding technology management, Vincent Boly.** How are R&T (research and technology) projects managed? How is a technology defined and understood? What are the stakes and the choices made on technologies? How do you measure the maturity of technologies, choose your key technologies, and manage your investments, intellectual property and partnerships?

Class components (lecture, labs, etc.)

The course consists of 10 thematic sessions of 3 hours each. Each session includes a TD of 30 minutes to 1h30.

Grading

The exam is a continuous examination (counted as 10 hours) based on a case study, in the context of a company, which is provided to students, in groups of 5 students, at the beginning of the course. They will conduct a mini-study to understand the context and structure a strategy and processes for managing Research, Devlopement and Innovation using the successive approaches they will see.

Course support, bibliography

- Cantamessa M., Montagna F., 2016. Management of innovation and product development - Integrating business and technological perspectives, London: Springer.
- Boly V., 2004. Ingénierie de l'innovation : Organisation et méthodologies des entreprises, Paris: Hermes Lavoisier.
- Cuisinier, C., Vallet, E., Bertoluci, G., Attias, D. & Yannou, B., 2012. Un nouveau regard sur l'innovation - un état des pratiques et des modèles organisationnels dans les grandes entreprises, Paris: Techniques de l'Ingénieur, ISBN 978-2-85059-130-3.
- Yannou, B. & Farel, R. eds. 2011. Déployer l'innovation : Méthodes, outils, pilotage et cas d'étude, Paris: Techniques de l'Ingénieur, ISBN 978-2-85059-129-7. Accès direct à ces fiches pratiques à http://www.techniques-ingenieur.fr/fiche-pratique/genie-industriel-th6/deployer-l-innovation-dt30/ de Centrale

- Yannou B., Bigand M., Gidel T., Merlo C., Vaudelin J.-P., 2008. La conception industrielle de produits - Volume I : Management des Hommes, des projets et des informations, Paris: Hermès Sciences, Lavoisier, ISBN 2-7462-1921-2.
- Yannou B., Robin V., Micaelli J.-P., Camargo M., Roucoules L., 2008. La conception industrielle de produits - Volume II : Spécifications, déploiement et maîtrise des performances, Paris: Hermès Sciences, Lavoisier, ISBN 2-7462-1922-0.
- Yannou B., Christofol H., Troussier N., Jolly D., 2008. La conception industrielle de produits - Volume III : Ingénierie de l'évaluation et de la décision, Paris: Hermès Sciences, Lavoisier, ISBN volume 3 978-2-7462-1923-6, ISBN général 978-2-7462-1920-4.
- Boly V., "Ingénierie de l'innovation : Organisation et méthodologies des entreprises", Hermes Lavoisier, Paris, 2004.
- Villemeur A., David E., Langrognet E., Massip S., Payonne J., Yannou B., Zebrowski A., Zimmer B., "Innovation Ouverte : 10 recommandations pour plus d'innovation et de compétitivité". Hors-série de la revue Centraliens, Centraliens, 2015.
- ISO 56002 - Innovation Management System

Resources

Teaching team (names of the teachers of the lectures):

- **Vincent Boly** is a University Professor at the INP Lorraine. He works on innovation engineering and technology management.
- **Michel Guiga** is Director of the innovation and performance consulting activity of Sogeti High Tech R&D (Capgemini Group).
- **Arnault Leservot** is in charge of industrial partnerships for research infrastructures at the Ministry of Higher Education, Research and Innovation (MESRI). In this capacity, he is in charge of the socio-economic and industrial impact of French research infrastructures, within the French Ministry of Higher Education, Research and Innovation. In this capacity, he leads teams in liaison with industry to provide technologies or conduct research with research infrastructures. He was previously in charge of industrial partnerships at the CEA, where he held various positions of responsibility in research and innovation.
- **Stéphane Martinot** is Research and Innovation Director at Valeo Powertrain Systems.
- **Patrick Ternier** is Founder and CEO of Innovation Framework Technologies, previously CEO of an American company listed on NASDAQ.
- **Emilie Vallet** has been supporting the innovation and transformation strategies of major international groups for more than 15 years.
- **Eléonore Venin** is President of Innovation & Strategy Partners (I&SPartners).
- **Bernard Yannou** is a Distinguished Professor of Design Engineering, Director of the Industrial Engineering Laboratory (LGI) at CentraleSupélec and Deputy Director of Research in charge of developing deeptech entrepreneurship.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:

- Know all the stages of the innovative company: its ecosystem, its strategy, its R&D, its innovation management and its projects for the development of new products / services / business models.
- Understand the professions of innovation and intrapreneurship: professions of chief innovation officer, manager-engineer of sustainable innovation, interface roles on the value chain as innovation project manager, open innovation development manager...
- Understand the links between the company's strategy and the theories and methodologies of innovation management, technology management, development engineering, product design and launch.

Description of the skills acquired at the end of the course

In general, from the CentraleSupélec Skills framework:

C3 – Milestone 3	Act, undertake and innovate in a scientific and technological environment
C4 – Milestone 3	Have a sense of creating value for one's company and one's clients
C8 – Milestone 3	Lead a project, a team

3GS3020 – Design Engineering

Instructors : **François CLUZEL**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **50**
On-site hours (HPE) : **30,00**

Description

Product Design in a broad sense (goods, services, business models) is one of the main missions of an Engineer (Eiffel, Michelin, Peugeot, Le Baron Jenney, Bouygues... were designers). Design Engineering is part of Industrial Engineering; it aims at investigating and defining the needs for a new product, and at implementing a design process to propose technical requirements, prototypes and performance validations in a limited time, with a limited project budget and with a total product cost (including purchase, ownership, maintenance and end-of-life) aligned with the willingness to pay of clients, to ensure the profitability of the company. The course Design Engineering will introduce the main methods and tools for the different stages of such a design process (define the need, specify, generate, validate). A particular focus will be done on methods and tools for Sustainable Design all along the sessions to prepare the Sustainable Design Challenge. One or several case studies will be used as a common thread to apply the different methods and tools on a same product to redesign.

Quarter number

SG10

Prerequisites (in terms of CS courses)

SD9 GSI

Syllabus

One or several projects will be used as a common thread for the tutorial classes. Students work in group. The case study of last year's course was a solar LED lantern.

1. Introduction to Design Engineering
2. Define the need I: this lecture deals with the identification of opportunities to create a new product, and the structured definition of design objectives. Methods and tools: users characterization, usage situations, creation of product usage scenarios...
3. Define the need II: this lecture complements the previous one by bringing methods and tools integrating the environmental dimension. Methods and tools: Life-Cycle characterization, environmental evaluation of a product to redesign, integration of impact during the use phase...
4. Specify I: this lecture deals with the characterization of the functions of a production and the specification of its performances to satisfy the clients' needs. Methods and tools: Functional Analysis, Quality Function Deployment.
5. Specify II : this lecture complements the previous on by showing how to integrate the environment in Functional Analysis. Methods and tools: Functional Analysis & Eco-design, Functional Unit definition.
6. Generate I: this lecture deals with the way to generate design alternatives for a new product while exploring the solution space. Methods and tools: exploration of product architectures (morphological matrices), FAST diagram.
7. Generate II: this lecture complements the previous one with a focus on eco-design, service design and sustainable business model design tools. Methods and tools: eco-design tools, service design tools (service blueprinting), sustainable bysiness models tools.
8. Validate I: this lecture deals with prototyping to illustrate concepts, and methods to compare design alternatives based on expected performances. Methods and tools: prototyping, validation, subjective and sensorial evaluation, multiobjective evaluation, Value Analysis.
9. Validate II: this lecture complements the previous one by showing how to integrate the environmental dimension in Value Analysis, and environmental evaluation in validation. Methods and tools: Value Analysis & Eco-Design, comparative environmental evaluation.
10. Final exam : case study in group.

Class components (lecture, labs, etc.)

An introductory lecture with interactive exercices + 8 sessions in a format lecture + tutorial class, and a final exam based on a case study.

Grading

Individual quiz on each session (50%) + case study in group (50%) ; in the case study, the students will build a scientific reasoning to design a product or a service by selecting, justifying and articulating the most relevant approaches to reach the objectives.

Course support, bibliography

-Cross, N. (2008). Engineering Design Methods-Strategies for product design. Fourth ed. Chichester: John Wiley& Sons, Ltd.

-Ulrich K.T., Eppinger S.D. (2016). Product Design and Development. Sixth ed. New-York: Mc Graw Hill Education.

-Yannou, B., Bigand, M., Gidel, T., Merlo, C. & Vaudelin, J.-P. eds. 2008. La conception industrielle de produits - volume i : Management des hommes, des projets et des informations, Paris: Hermès Sciences, Lavoisier, ISBN 2-7462-1921-2.

-Yannou, B., Robin, V., Micaelli, J.-P., Camargo, M. & Roucoules, L. eds. 2008. La conception industrielle de produits - volume ii : Spécifications, déploiement et maîtrise des performances, Paris: Hermès Sciences, Lavoisier, ISBN 2-7462-1922-0.

-Yannou, B., Christofol, H., Troussier, N. & Jolly, D. eds. 2008. La conception industrielle de produits - volume iii : Ingénierie de l'évaluation et de la décision, Paris: Hermès Sciences, Lavoisier, ISBN volume 3 978-2-7462-1923-6, ISBN général 978-2-7462-1920-4.

Resources

Teachers:

- François Cluzel, assistant professor at LGI
- One or several PhD students from LGI

Learning outcomes covered on the course

At the end of this course, students will be able to:

- Understand the main approaches in design engineering, with a particular focus on sustainable design
- Master and implement the different stages of a complete design process
- Select and apply different tools for designing products, services or business models in a perspective of utility (human-centered design, Value Analysis) and sustainability (sustainable design)

Description of the skills acquired at the end of the course

C1. Analyze, design, and build complex systems with scientific, technological, human, and economic components
C3 Act, undertake, innovate in a scientific and technological environment
C4. Have a sense of value creation for his company and his customers
C9. Think and act as an ethical, responsible, and honest engineer, taking into account the environmental, social, and societal dimensions

3GS3030 – Sustainable Design Challenge

Instructors : **Yann LEROY, Franck MARLE**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **50**
On-site hours (HPE) : **30,00**

Description

The *Sustainable Design Challenge* aims to immerse students in a design or re-design project with a solid sustainable dimension (Environmental, Social, Societal, and Economic).
Based on a problem observed and qualified by a customer, the students will have to propose a conceptual solution responding to the problem. Students must justify all choices made during the exploration and synthesis phases. The quality of the justification for the choices made, and in particular, the presentation, even if brief, of the alternatives not chosen, is as crucial as the quality of the solution chosen.
A detailed description, a feasibility study, and a first physical or virtual prototype must accompany solutions.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

- Presentation of topics by companies: issues and expectations
- Project progress up to an intermediate presentation to a jury (first design phases including initial solution elements).
- Project progress up to a final presentation to a jury including the customer.
- Intermediary points outside the presentations (number and position to be determined with supervisors and customers), in the form of progress reviews or work meetings.

Class components (lecture, labs, etc.)

Project, workshops, methodological and technical support

Grading

Evaluation of group work, with individual adjustments possible, based on presentations and project deliverables. These elements will be evaluated by a panel made up of the industrial partners and the supervising educational team.

Course support, bibliography

See Design Engineering course

Resources

Classrooms, whiteboard, small prototyping equipment, sound/video equipment for plenary sessions
plenary sessions (mini-courses, lectures, intermediate and final presentations)

Learning outcomes covered on the course

The SD Challenge aims to develop the following competencies:

- Understand the client’s need
- Launch an innovative design project
- Understand and evaluate the issues of sustainable design (including the Sustainable Development Objectives)
- Conduct a project under agile management principles

Description of the skills acquired at the end of the course

At the end of the challenge, the student will be assessed on:

C1 Analyse, design and implement complex systems made up of scientific, technological, social and economic dimensions.
C3 Act, engage, innovate within a scientific and technological environment
C9 Think and act as an ethical, responsible and honest engineer, taking into account environmental, social and societal dimensions

3GS3040 – Master Classes Design Science

Instructors : **François CLUZEL, Flore VALLET**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **15**
On-site hours (HPE) : **9,00**

Description

The Master Classes "Design Science" complements the Design Engineering course. They will allow the students to discover profesionnal contexts and activities in connection with design engineering and for which they are not familiar. Students will meet professionals from Resarch, Industrial Design and Innovation in companies.

Quarter number

SG10

Prerequisites (in terms of CS courses)

SD9 GSI

Syllabus

1. Workshop "Research in Design Science": 3-hours workshop organized by and with the Design Engineering Research Group at LGI; students will meet researchers (yes, theirs teachers are also researchers!), including in particular the PhD students. Students will organize (before the workshop) and will animate a round table to understand on one side the role of a researcher, and on the other side the typical objects and results of a research work in this field.

2. Workshop "Practices of Industrial Design": 3-hours workshop organized by the design studio UNITS, with a positioning between engineering and design; this workshop will allow the students to discover the job of an industrial designer, too often unrecognized by engineers, and the links with engineering.

3. Workshop "Consultancy in Innovation": 3-hours workshop organized with the consultancy firm MEWS Partners. Adrien Gros (Centralien) will propose an interactive presentation on how design methods, tools and processes should support innovation in industry, based on his strong experience in different sectors. He will raise subjects like continuous improvement, agile management, lean, date usage, R&D performance; the speach aims at immersing students the reality of design and innovation projects in industry, with the eye of a consultant. He will also question the role of students as future engineers in this ecosystem.

Class components (lecture, labs, etc.)

Three thematic workshops organized on or oustide of the campus.

Grading

Validation on attendance + delivery of a professional project report

Resources

Speakers:

- Flore Vallet, assistant professor at the Industrial Engineering Research Department (LGI) of CentraleSupélec and at IRT SystemX
- François Cluzel, assistant professor at LGI
- Yoann Montenot, designer at the Design Sport of Université Paris-Saclay
- Adrien Gros, senior consultant at Mews Partners, alumnus of Ecole Centrale Paris
- Researchers and PhD students from the research group Design Engineering of LGI

Learning outcomes covered on the course

At the end of this course, students will be able to:

- Be aware of different industrial contexts and actors in connection with Design Science and take a step back on them
- Understand what is a Research activity in Design Science
- Understand the role of an industrial design, its specificties and complementarities with the role of an engineer
- Understand the role of Innovation in different industrial contexts

Description of the skills acquired at the end of the course

C2. Develop in-depth skills in an engineering field and a family of professions

3GS3050 – Innovation Engineering

Instructors : **Marija JANKOVIC, Stéphane Savelli**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Innovating on an engineering system requires (a) a clear and ambitious project parameterization (b) accurate analytical tools allowing the identification of promising innovation directions and key problems to solve (c) efficient problem-solving tools (d) a tool to evaluate conceptual solutions. Therefore, this requires an engineering approach to innovation. In this course, one such approach is presented: TRIZ. The main application of this method is to improve significantly industrial products or processes or to develop new ones. Many global companies use it, including General Electric, Siemens, Samsung, Hyundai, Philips, Arcelor Mittal.
The objective of this course is to teach the basic tools of TRIZ, and to put them immediately into practice on a non-trivial use case (if possible, a real engineering innovation project submitted by an industrial company), so as to be able to reuse this approach later in a project context.
Each student will be able to receive a MATRIZ (TRIZ International Association) level 1 certificate offered by CentraleSupélec, under the condition of success at an individual test.

Quarter number
SG10

Prerequisites (in terms of CS courses)
No prerequisite

Syllabus

The objective of the course is to teach you how to innovate on engineeringl systems (industrial products and processes) using some basic TRIZ tools that you will apply directly to real problems.
TRIZ is a romanized Russian acronym meaning "theory of inventive problem solving". It was invented in the USSR in 1948 by Genrikh Altshuller. After an initial analysis of 200,000 patents (big data!), he discovered that engineering inventions follow universal patterns, independent of the technical field in question. The practical corollary of this discovery is that knowing these patterns allows to innovate more efficiently.
The modern version of TRIZ now focuses on technical innovation: it goes beyond problem solving to identify the key problems that need to be solved. When faced with a difficult technical problem that arises at any phase of a development project or for the particular "front end of innovation" phase, TRIZ guides engineers in a structured way towards the most valuable innovative design solutions.
The course comprises the following elements: introduction to TRIZ and its history, psychological inertia, MPV (Main Parameters of Value) analysis, benchmarking of technologies, function analysis, value analysis, cause-and-effect chain analysis, conceptual directions and key problems, resource analysis, function-oriented search, pairs of engineering contradictions and Altshuller matrix, physical contradictions and their resolution principles, secondary problem solving, evaluation of conceptual solutions.
Students will model part of their project on the free graphic editing software yEd (https://www.yworks.com/downloads#yEd).

Class components (lecture, labs, etc.)

The course will be well-balanced between the presentation of TRIZ tools and concepts (with examples and didactic exercises) et their direct application on a use case / project.
The teacher will present two non-trivial case studies / projects to be chosen by the students. The students will then form groups of four and apply the TRIZ tools step by step, under the guidance of the teacher. The students will carry out a part of their work out of the classroom (6h), as well as the writing of their report / presentation on PowerPoint.

Grading

The final grade will be a weighted sum of their projects' report and presentation (80%) and their individual, MATRIZ level 1 certification test (20%).

Course support, bibliography

Short biography of Genrikh Altshuller: https://matriz.org/about-matriz/about-founder/
A TRIZ retrospective analysis of a smartphone folding screen patent application by Valeriy Prushinskiy, TRIZ Master: https://www.youtube.com/watch?v=04GulCuHtcw
A TEDx conference with Sergei Ikovenko, TRIZ Master, introducing the trends in the evolution of technical systems: https://www.youtube.com/watch?v=cCLFJ_QxM4E&t=11s

Resources

Teaching team (names of the teachers of the lectures):
Stéphane Savelli, founder and managing director of MP Solving, ECP Engineer & University of Stuttgart, Doctor in Material Sciences and Engineering, TRIZ level 3 practitioner. 15 years of previous experience in industry (R&D, design office, industrialization, production support). 10 years of experience in TRIZ-based services.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:

- Understand the main concepts and tools of basic TRIZ
- Put into practice the solving of an innovation problem on an engineering system through the different steps of TRIZ
- Build function models and cause-and-effect chains for products
- Formulate pairs of engineering contradictions and solve them with the Altshuller matrix
- Formulate and resolve physical contradictions

Description of the skills acquired at the end of the course

In general, from the CentraleSupélec Skills framework:

C3 - Act, undertake, innovate in a scientific and technological environment
C4 - Have a sense of value creation for his company and his customers
C8 - Lead a project, a team

3GS3060 – Data-driven Design Analysis

Instructors : **Marija JANKOVIC, Walid Ben Ahmed, François CLUZEL**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The aim of this teaching module is to provide students with methods to design efficient, robust and reliable systems. A particular focus is made on the methods using as input: data about the product/service to be designed, their users as well as their use conditions.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Basic knowledge in probability and statistics

Syllabus

1. Datamining for Design: Factor analysis, Classification, Clustering, Bayesian Networks, Decision tree, Association rules
2. Optimal Design: application of Design Of Experiments (DOE) to 1) Assess the effect of multiple factors on a system behavior 2) Build a model of system behavior; 3) Determine the optimum design to maximize a system performance
3. Robust Design: application of crossed DOE (design factors x noise factors) to: 1) Assess the influence of design parameters on a system robustness; 2) Determine the technical choices ensuring the robustness of the system
4. Reliable Design: Reliability laws / Accelerated Life Testing / Test design to demonstrate the reliability of a syste

Class components (lecture, labs, etc.)

- 4h lecturing + 2h tutorial classes about the application of Datamining techniques in order to build product models et use these models in design
- 3h lecturing + 1 tutorial classes about the application of DOE (Design Of Experiments) to optimize a system behavior
- 3h lecturing + 1 tutorial classes about the application of DOE to robustify a system behavior
- 3h lecturing + 1 tutorial classes about the application of Design For Reliability, with a focus on the sizing of Accelerated Life Tests

Grading

- MCQ: Assess the student knowledge and understanding of the Datamining methods principles and their use in design Synthesis and in Design Analysis
- MCQ: Assess the student knowledge and understanding of DOE methods and their use in design optimization
- MCQ: Assess the student knowledge and understanding of DOE methods and their use in robust design
- MCQ: Assess the student knowledge and understanding of quantitative methods of Design For Reliability and their use to assess the reliability of a system

Course support, bibliography

Formal engineering design synthesis, EK Antonsson, J Cagan - 2005
Data mining for design and manufacturing: methods and applications, D Braha - 2013
Statistics for Experimenters: Design, Innovation, and Discovery, 2nd Edition, by George E. P. Box (Author), J. Stuart Hunter (Author), William G. Hunter
Accelerated Testing: Statistical Models, Test Plans and Data Analyses (Wiley Series in Probability and Mathematical Statistics-Applied Probability), by Wayne Nelson, Published 1990

Resources

Videoprojector
Personnel laptop

Learning outcomes covered on the course

At the end of this course, the student will be able to:

- Create and use data for "Design Synthesis": convert subjective criteria expressed by the client into physical design criteria)
- Create and use data for "Design Analysis": assess the impact of design technical specifications on customers perception/satisfaction
- Create and use data to optimize the performance of a system: find the set of parameters to achieve an optimum design allowing to maximize the performance of a system
- Create and use data to robustify the functioning of a system: find the set of parameters to reduce the sensitivity of a system's performance to its use environment
- Create and use data to design reliable system: carrying out optimum tests in terms of number of samples and duration to demonstrate the reliability of a system

Description of the skills acquired at the end of the course

C1 Analyze, design, and build complex systems with scientific, technological, human, and economic components
C6 Be operational, responsible, and innovative in the digital world

3GS3080 – Seminar Design & System Sciences

Instructors : **François CLUZEL, Marija JANKOVIC**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **5**
On-site hours (HPE) : **3,00**

Description

A half-day information on the curricula and get together
Give information related to curricula such as courses, internships, etc.
Team building activity with one of the partners of the mention

Quarter number

SG10

Prerequisites (in terms of CS courses)

SD9 GSI

Grading

Mandatory

Description of the skills acquired at the end of the course

C1. Analyser, concevoir et réaliser des systèmes complexes à composantes scientifiques, technologiques, humaines et économiques

3GS3110 – Design of resilient systems

Instructors : **Marija JANKOVIC, François CLUZEL, Yiping FANG**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The main objective of this course is to introduce the issues related to the design of resilient systems, their treatment by modeling tools and their integration into an operational management process. The sessions are organized around case studies or issues.
The course benefits from the industrial environment created by the Risks and Resilience Chair in Complex Systems. Variations are possible on use cases. They are defined in such a way as to give a varied sample of the problems of risk analysis and resilience in design.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Basic knowledge in probability, statistics Monte Carlo simulation, modelization

Syllabus

Lecture 1 - Introduction, concepts (risk, reliability, robustness, safety,resilience phases), FMEA, HAZOP
Lecture 2 - Performance calculation (FT), network reliability, simulation, network flow model
Lecture 3 - Reliability-oriented optimization, heuristics applied to reliability(GA, PSO)
Lecture 4 - Use case
Lecture 5 - Use case
Lecture 6- Final exam

Class components (lecture, labs, etc.)

Courses, Practical work, Industrial presentations, Exchanges around use cases.

Grading

Papers reading and examination - 3 hours

Course support, bibliography

Slides, Documents provided by industry partners

Resources

- Teaching team
  - Anne Barros, Zhiguo Zeng, Yiping Fang
  - Industrial external contributors

- Materials: Collection of transparencies and documentation relating to use cases
- IT tools: Python / Matlab / Industrial software tools

Learning outcomes covered on the course

- Understand the concepts of risk and resilience for a complex system
- Understand the challenges to analyze and model the resilience of complex systems
- Have a global vision with different modeling techniques, their framework of use, their assets and their limits
- Understand how models are used and influence decision-making processes in the design and operation of complex systems
- Understand what are the current operational and managerial challenges for the resilience of complex systems

Description of the skills acquired at the end of the course

C1 Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2 Develop in-depth skills in an engineering field and a family of professions
C6 Be operational, responsible, and innovative in the digital world

3GS3120 – Systems of Systems

Instructors : **Andreas-Makoto Hein**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Engineers of the future will be more and more concerned with the development of systems which are collaboratively integrated. Examples are multi-modal transport (bus, subway, trains, managed by different actors), energy distribution systems into which renewable energy sources are integrated (systems for energy production, distribution, and energy markets), air traffic management (airports, control centers, airplanes), healthcare systems (hospitals, information system, insurance), and cyber-physical systems (Industry 4.0 etc.). Such systems integrating systems in a collaborative manner (multiple actors which collaborate and manage the individual systems) are called “systems of systems”. Designing systems of systems faces challenges, which are not present in “traditional” systems (cars, airplanes, trains) and require specific competencies, namely, the development of collaborations, interoperability (protocols and standards for data exchange), incremental development and deployment, and the development of collaborative services. The main objective of this course is to present fundamental methods and tools for designing systems of systems (characterize the context with existing systems and actors, to design their evolution, to predict the impact on actors and society / the environment). These methods and tools are applied to an ongoing case study.

Quarter number
SG11

Prerequisites (in terms of CS courses)
SD9, SG10

Syllabus

Session 1 : Introduction to the notion of systems of systems ; Definitions and types of systems of systems (product service systems, cyber-physical systems, internet of things); typical domains where systems of systems are encountered (multi-modal transport, smart grid); introduction to design frameworks for systems of systems (NAF, DoDAF, etc.); Introduction to the design of systems of systems and differences to traditional systems engineering (Wave model, capability engineering, evolutionary design, collaboration design, legacy systems)

Session 2 : Selection and characterization of the context of a system of systems : Identification and characterization of existing systems, their interfaces, and actors who manage those systems. Characterization of the larger societal context, with technological, political, regulatory, and environmental trends.

Session 3 : Design of collaborative services and their integration into a system of systems. Modeling the collaborative services and design process.

Session 4 : Generation of alternative systems of systems, performance analysis and compatibility with their context ; integration of legacy systems and technologies, integration of new systems and technologies, definition of protocols and standards for interaction and data exchange.

Session 5 : Development of deployment scenarios - Design of transition trajectories from the current context, identification of potential barriers.

Session 6 : Principles and tools for the advanced analysis of systems of systems, for example, the design of rapidly reconfigurable systems of systems (search and rescue, internet of things)

Class components (lecture, labs, etc.)

- Use of case studies for illustration purposes and group work
- Industry talks
- Group work on case studies

Grading

Small exams during the course and deliverables for the project at the end of the course

Course support, bibliography

- Baldwin, W., Sauser, B., 2009. Modeling the characteristics of system of systems. Syst. Syst. Eng. 2009.
- Boardman, J., Sauser, B., 2006. System of Systems-the meaning of of, in: IEEE/SMC International Conference on System of Systems Engineering. p. 6.
- Hein, A., Poulain, B., Jankovic, M., Chazal, Y., Fakhfakh, S., 2018. Product Service System Design in a System of Systems Context: A Literature Survey, in: 15th International Design Conference Design 2018.
- Hein, A.M., Chazal, Y., Boutin, S., Jankovic, M., 2018. A Methodology for Architecting Collaborative Product Service System of Systems, in: 13th Annual Conference on System of Systems Engineering (SoSE). IEEE. pp. 53–59.
- Maier, M.W., 1996. Architecting Principles for Systems-of-Systems. INCOSE Int. Symp. 6, 565–573. https://doi.org/10.1002/j.2334-5837.1996.tb02054.x

Resources

- Team of lecturers: Andreas Hein and other lecturers, PhD students of LGI (to be defined)
- Size of TD (by default 35 students): 40 students maximum
- Software and licences required: no
- TP rooms (department and capacity): no

Learning outcomes covered on the course

- Know the difference between « traditional » systems and systems of systems
- Know the types of systems of systems
- Apply one approach for the design of systems of systems to a case study
- Model key aspects of a system of systems
- Model the context of a system of systems (societal, technological, environmental, political, and regulatory aspects)
- Analyze the performance of a system of systems
- Generate alternatives for systems of systems

Description of the skills acquired at the end of the course

C1 Analyze, design, and build complex systems with scientific, technological, human, and economic components
C8 Lead a project, a team

3GS3130 – Human-Systems Integration

Instructors : **Guy-André Boy, François CLUZEL, Marija JANKOVIC**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

This course is based on Human-Centered Design (HCD) and associated practice in the development of virtual prototypes that requires progressive operational tangibility toward Human-Systems Integration (HSI). It introduces flexibility in design and operations, tangibility of software-intensive systems, virtual HCD, increasingly autonomous complex systems, Human-Factors and Ergonomics of sociotechnical systems, and systems of systems integration. This course introduces a fundamental systemic approach to HSI, in terms of maturity, autonomy, human-machine teaming, complex organizations, and change management, especially in digital organizations. This course is an in-depth introduction to Human-Systems Integration (HSI) that associates Human-Centered Design (HCD) to Systems Engineering to integrate human and organizational knowledge, methods and tools to fulfil requirements leading to successful sociotechnical systems. It is organized in two parts: (1) HSI: Managing Complexity of Technology, Organizations and People; and (2) Human-Centered Design of Autonomous Systems. Main objective is to provide HSI knowledge and organize real-world use cases development activities with external industrial support.

Quarter number

SG11

Prerequisites (in terms of CS courses)

No prerequisite in addition to basic STEM disciplines.

Syllabus

1. Human-System Integration: Managing Complexity of Technology, Organizations and People
Course syllabus on 11 HPE + 4 additional HEE:

a. Introduction to Human-systems integration (HSI) design and management [1 HPE]
b. Cognitive engineering (human modeling for human issues evaluation) – cognitive function analysis – structure function modeling including people – theories of natural and artificial systems [3 HPE]
c. Organization design and management and complexity analysis of sociotechnical systems – agile engineering of systems and associated human factors [2 HPE]
d. Scenario-based design and human-in-the-loop modeling and simulation (activity analysis) – physical and figurative tangibility – digital twins [2 HPE]
e. HSI exercises (participatory design, formative evaluation…) [2 HPE + 4 additional HEE]
f. Mid-term exam (written) [1 HPE]

2. Human-Centered Design of Autonomous Systems
Course syllabus on 7 HPE + 8 additional HEE:

a. Automation evolution – human-systems cooperation, delegation and trust [1 HPE]
b. Autonomy: definitions, discussions and synthesis – models and metrics – teams of teams [1HPE]
c. From rigid automation to flexible autonomy (levels of autonomy) – evaluation and certification [1 HPE]
d. A real-world case (one of three) [2 HPE + 8 additional HEE]
1: automotive or aeronautics (possibly with IFSTTAR and/or Safran)
2: robotics (possibly with Total)
3: air combat (possibly with French Air Force)
e. Final exam (written and oral) [2 HPE]

Class components (lecture, labs, etc.)

- In Part 1, the sequence is from (a) to (f), and in (e) first HPE is to state the problem, the 4 additional HEE are devoted to homework for solving exercise problems, and second HPE to review students' problem solving and solutions. Mid-term exam is a formal exam testing knowledge acquisition.

- In Part 2, the sequence is from (a) to (e), and in (d) first HPE is to state problem(s), the 8 additional HEE are devoted to home work for processing the chosen real-world case – possibly some work could be done with an industrial partner related to the case, and second HPE to review students' problem solving and solutions. Final exam is in the form of a written report submitted a few days before an oral presentation of real-world case solutions.

- Note that additional invited talks could be given by industrial partners (they could be either mandatory and replace 1 HPE each or additional but highly recommended).

Grading

Evaluation (Modalities and weights of each evaluation in the final score: final exam, mid-term exam, written, oral, project…): Mid-term exam will be scored with respect to performance on the written test. Final exam will be scored with 50% on written report quality and 50% on oral presentation of work done on the real-world case.

Course support, bibliography

- Design for Flexibility: A Human Systems Integration Approach, by Guy André Boy, Springer Nature, Switzerland, 2021.
- Human Systems Integration: From Virtual to Tangible, by Guy André Boy, CRC–Taylor & Francis, USA. 2020.
- Orchestrating Human-Centered Design, by Guy André Boy, Springer, USA. 2013.
- Tangible Interactive Systems, by Guy André Boy, Springer, USA. 2016
- Slides of the classes and additional articles on HSI.

Resources

Teaching team: Guy André Boy and HSI colleagues
Labs volume (around <TBD> students): possibly use of DIGISCOPE
Software tools and number of required licenses: N/A
Lab rooms (department and capacity): regular classroom

Learning outcomes covered on the course

At the end of this course, students will be able to :

- Take into account human and organizational factors in the design of complex sociotechnical systems in order to improve safety, efficiency and comfort.
- Know and understand the main principles of human systems integration (HSI) and apply them to the development of complex human-machine systems design.
- Have the mindset of referring to HSI anytime complex human-machine systems design and development will be concerned.
- Know about and be able to apply HSI principles and human-in-the-loop simulation in the context of life-critical system design.
- Know about and implement design and operations flexibility, tangibility in virtual HCD, maturity and sociotechnical stability in the context of life-critical system design.
- Know about and apply main human-centered metrics and (socio) cognitive complexity analysis in the context of life-critical system design.

Description of the skills acquired at the end of the course

C1 Analyse, design and implement complex systems made up of scientific, technological, social and economic dimensions.
C4 Create value for companies and clients
C6 Advance and innovate in the digital world
C7 Strengthen the Art of Persuasion
C8 Lead a team, manage a project

3GS3140 – Complex Project Management

Instructors : **Franck MARLE**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

System design projects cover many dimensions regarding the number of objectives pursued simultaneously and the number of stakeholders involved. Moreover, the temporality of objectives is essential since a project may last a few years but have consequences over several decades.

These numerous, diverse, and interdependent parameters, evolving in a dynamic environment, give projects high complexity. That makes it more or less challenging to make decisions, not only on the What, the result of the project, but also on the How, the process and the organization that will deliver this result.

This course module aims to discover techniques that take this complexity into account and the emergence of more distributed project management methods.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Block 1: Towards integrating complexity into decision-making, application to project risk management
- Basic analysis and action plan
- Modeling interdependencies between risks
- Interdependency network analysis (topological, propagation, vulnerability)
- Action plans, using a constant structure and modifying the structure to adapt it to the complexity of the network (clustering by interdependence)
- Opening up to the need for more distributed management modes to take account of this complexity.

Block 2: Towards integrating distributed management into decision-making on complex projects
- Distributed management 1: holacracy, which can be applied at multi-project and single-project levels
- Distributed management 2: agility, which can be applied at both single and multi-project levels
- Combination of distributed management and taking into account the complexity and interdependencies seen in block 1

Class components (lecture, labs, etc.)

Lectures / case studies

Grading

Assessment is in the form of two reports corresponding to the two blocks of the course. These assignments are started during the sessions and are due a few weeks after the end of the course.

Resources

No specific software license or material (except laptop).

Learning outcomes covered on the course

At the end of the course, students will have made progress on the following aspects:

- Advanced techniques for managing project risks and opportunities, taking into account their interdependencies,
- Emerging, more distributed, and less hierarchical management techniques
- Advantages and disadvantages of these techniques, particularly when combined.

Description of the skills acquired at the end of the course

C1 Analyze, design, and build complex systems with scientific, technological, human, and economic components
C4 Create value for your company and your customers
C9 Think and act as an ethical, responsible, and honest engineer, taking into account environmental, social, and societal dimensions.

3GS3150 – Digital transformation for organizations

Instructors : **Pascal MORENTON**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The "Digital Challenge" is a case study in the digital transformation of an organisation's operations. Methodological elements will be presented and students will be invited to carry out a project management assistance mission to help an organisation achieve its digital transformation and provide support. This study is a first approach to the problems associated with the digital transformation of companies and organisations and the methodologies to be deployed to address these issues.

Quarter number

SG11

Prerequisites (in terms of CS courses)

non prerequisite

Syllabus

The course will take the form of a 3.5-day "challenge" with the following structure:

- 1st half-day: presentation of the course, the fundamentals related to the areas covered; presentation of the case study and the expectations; start of group work;
- During 3 days: work on the case study and theoretical contributions to facilitate the treatment of the case study; work in groups; preparation of the deliverables;
- Last half-day: support and presentation of deliverables; debriefing and synthesis.

Class components (lecture, labs, etc.)

To allow an active pedagogy particularly adapted to the target audience, this course will be structured around a case study where different stakeholders can intervene. The students will then be invited to take on the role of "consultants" in charge of accompanying a company or organization in its digital transformation and to respond to a mission that will be defined.

Grading

Evaluation of a mini-project with final defense.

Resources

Learning outcomes covered on the course

Description of the skills acquired at the end of the course

C1 Analyze, design, and build complex systems with scientific, technological, human, and economic components
C4 Have a sense of value creation for his company and his customers
C6 Be operational, responsible, and innovative in the digital world
C7 Know how to convince
C9 Think and act as an ethical, responsible, and honest engineer, taking into account the environmental, social, and societal dimensions

3GS3155 – Makerspace Challenge "Product-Service design and IoT prototyping"

Instructors : **Samuel Gomes**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course aims to provide the fundamentals, methodologies and tools for Product-Service System (PSS) through Cyber Physical System (CPS) design and innovative Internet of Things (IoT) prototyping project, engaging students in practical experiences inside a dedicated collaborative work space: the CentraleSupelec Makerspace. IoT is a specific typology of CPS, as IoT is about connecting "Things" (Objects and Machines) to the Internet and also to each other; while CPS are integration of computation, networking and physical systems/process as a result of a Product-Service design process.

In this course, students get to explore innovative design and engineering processes and put their scientific, technical and business skills to the design of a CPS, as a PSS solution to an identified customer need, and to experiment fast-prototyping of an innovative IoT. This course is organized around 2 main topics:

1- PSS design & innovation approach including lean innovation methods such as design thinking, information gathering techniques in order to identify problems and imagine innovative solutions for cities, citizens, associated companies or industries with in-situ data captured on the explored field.

2- Fast-prototyping approach of an innovative IoT concept:

- learn how to build and use a Minimum Viable Product (MVP) to validate/invalidate assumptions
- build a prototype to iterate and refine the solution developed (product or product-service) using fast-prototyping tools available at CentraleSupelec Makerspace such as: 3D modeling, 3D printing, laser-cutting, CNC, etc. for the hardware, and IoT fast-prototyping platform including sensors actuators and cloud computing environment, etc. for the electronic, middleware and software
- experiment interdisciplinary design and engineering workshops

Quarter number

SG11

Prerequisites (in terms of CS courses)

No prerequisite

Syllabus

1. "Lean Engineering" versus "Lean innovation" and Systemic design approach of Product-Service Systems and Cyber Physical Systems
2. Introduction to management of collaborative projects and to collaborative design tools - Application of SADT method to the project (identification of tasks, expected results and scheduling) – Validation of team projects
3. Methods and tools for information collection of the domain and Basics of External Functional Analysis
4. Design and fast-prototyping of basic architectures and programming of CPS including Sensors / Actuators / Controller / Transceiver / Cloud visualization (feeders and dashboards)
5. Creative design methods and tools (FAST, C-K and Internal Functional Analysis) for innovative CPS design
6. 3D Modeling and rapid prototyping of mechanical parts
7. IoT controller and software programming (TOKYMAKER + Cloud data management)
8. Use case application and project defense in CentraleSupelec MAKERSPACE

Class components (lecture, labs, etc.)

Traditional lectures and practical sessions will help the students to understand PSS challenges and specify, design, calculate, program and finally prototype the Minimum Viable Product of their CPS concept.

Grading

Project evaluation (Project report, final pitch, Minimum Viable Product demonstration)

Course support, bibliography

NA

Learning outcomes covered on the course

Along the various chapters of this course, engineering students must demonstrate :

- ability to understand challenges of PSS design and engineering in our digital society
- ability to develop, to design new and complex products (devices, artefacts, etc.), processes and systems, with specifications incompletely defined and/or competing, that require integration of knowledge from mechanical engineering, material science, electronics, computer science as well as non-technical - societal, health and safety, environmental, economic and industrial commercial – constraints; to select and apply the most appropriate and relevant design methodologies or to use creativity to develop new and original design methodologies.
- ability to design using knowledge and understanding at the forefront of engineering specialization.
- workshop skills and ability to design and conduct experimental investigations, critically evaluate data and draw conclusions;
- comprehensive understanding of applicable materials, equipment and tools, engineering technologies and processes, and of their limitations;
- ability to operate effectively in real design project contexts, as a member or leader of a team, that may be composed of different disciplines and levels, and that may use virtual communication tools.

Description of the skills acquired at the end of the course

C3 Act, undertake, innovate in a scientific and technological environment.
C8 Lead a project, a team.
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3GS3160 – Master Classes System Science

Instructors : **Marija JANKOVIC**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **10**
On-site hours (HPE) : **6,00**

Description

« Master Classes » entitled « Simulation processes, system architecture design » represent a support for students to discover or explore professional contexts and job types that are relevant in the domain of complex system design. The classes put together professionals and students through workshops or round tables to foster discussion around possible careers as well as possible professional evolution within this domain.

Quarter number

SG11

Prerequisites (in terms of CS courses)

No previous requirements.

Syllabus

1. « System Architecture design » workshop or round table : Workshop or round table aiming giving details for career possibilities in the domain of conceptual design, system architecting, technology development that are relevant for early system design (e.g. Portfolio manager, Innovation manager, Product manager, Commercial engineer, Proposal Engineer coordinator etc.). Students will be involved in the organization and the design of these 3 hours with regard to their particular questions.

2. « Simulation processes » workshop or round table: Workshop or round table that will address the careers in the later phases of the design such as Simulation engineer, V&V engineer, Simulation System Architect, etc. As for the previous workshop or round table, the organization will be discussed and put in place in order to best answer to student's questions in order to support them in the refinement of their professional project.

Grading

Presence and report.

Course support, bibliography

NA

Learning outcomes covered on the course

At the end of this course, students will be able to:

- Experience different industrial contexts and actors in Complex System engineering
- Understand what are the activities and job in System Architecting
- Understand the Simulation and Modeling of complex systems and related jobs

Description of the skills acquired at the end of the course

C1- Analyze, design and build complex systems with scientific, technological, human, and economic component
C2 - Develop in depth skills in an engineering field and a family of professionals

3GS3170 – Industrial Ecology

Instructors : **Yann LEROY, François CLUZEL**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY), MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Industrial Ecology is an approach aiming at limiting the impacts of Industry on the environment. It considers globally a industrial system to identify, model and optimize material and energy flows, as well as environmental impacts. Its goal is to reproduce, with human activities, a natural system where all material and energy flows are reused, where the notion of waste does not exist. Industrial Ecology is a key strategy to Implement Circular Economy. All industrial sectors are concerned. That is why Industrial Ecology is logically at the core of Industrial Engineering and Process Engineering!
This elective course is mutualized between the two "mentions" Design & System Sciences (Dominante GSI) and Environment - Sustainable Production (Dominante VSE). Its objective is to introduce the main concepts and principles of Industrial Ecology, that will be manipulated on a case study.

Quarter number

SG11

Prerequisites (in terms of CS courses)

SD9 GSI or VSE, SG10 GSI/Design & System Sciences or SG10 VSE/Environement - Sustainable Production

Syllabus

1. Introduction to Industrial Ecology & Material Flow Analysis (François Cluzel and/or Yann Leroy, François Puel): Introduction to Industrial Ecology bascis as a Circular Economy strategy towards an ecological transition; Illustration with examples of industrial synergies on French or international territories, for example the biorefinery of Pomacle-Bazancourt or the nickel plant Vale NC in New Caledonia; introduction to Material Flow Analysis as a tool to map material and energy flows of an industrial site.

2. Energy efficiency (Grégory Choppinet): Présentation of concrete energy efficiency projects in industry; presentation of energy audit tools and assessment of the feasibility, implementation and follow-up of a project; barriers of Industrial Ecology projects.

3. Industrial symbiosis (Andreas Hein): definition and illustration of the eco-industrial park concept; which are the main factors fostering the development of ambitious and long-lasting industrial symbioses? Which tools exist to support this development?

4. Economic and legal stakes (Geneviève Ferone-Creuzet): what is the existing or future regulatory framework in Industrial Ecology, in particular on waste statutes? Which are the associated business models? Which are the associated barriers and opportunities?

5. and 6. Case study: reconversion of an eco-industrial park (Jérémy Chen, Jérémie Benisti, Florian Bettini, Pierre Faure): the case study will last two sessions, in groups. It aims at proposing scenarios of reconversion of an industrial platform (case study inspired from a real case). Each group will lead an Industrial Ecology project for this site, will evaluate its technical and economi feasibility as well as the social and environmental impact. The construction of a viable reconversion project for the site will particularly rely on the identification of synergies and interactions between each projects and groups. The Energy Director from Cap Gemini will share his feedback of the real project at the end of the case.

If possible, a visit of the Paris-Saclay heat and cold network installations will be organized on a Thursday morning for the volunteer students.

Class components (lecture, labs, etc.)

- Lectures + tutorial classes
- Case study in group (on 2 sessions)

Grading

- Individual and online quiz (50%)
- Case study in group (50%)

Course support, bibliography

- Adoue, C., 2007. Mettre en oeuvre l'écologie industrielle. PPUR, Lausanne.
- Buclet, N., Barles, S., 2011. Ecologie industrielle et territoriale : Stratégies locales pour un développement durable. Presses Universitaires du Septentrion, Villeneuve d'Ascq, France.
- Erkman, S., 2004. Vers une écologie industrielle, 2e éd. ed. Charles Léopold Mayer, Paris.
- Hawken, P., Lovins, A., Lovins, L.H., 1998. Natural Capitalism: Creating the Next Industrial Revolution, 1st edition. ed. US Green Building Council, Boston.

Resources

Teachers :

- Yann Leroy and François Cluzel, Assistant Professors at the Industrial Engineering Research Department (LGI)
- François Puel, Professor at the Material and Process Engineering Research Department (LGPM)
- Andreas Hein, Researcher/System architect, IRT SystemX
- Grégory Choppinet, CEO, Lemon Energy
- Geneviève Ferone Creuzet, Casabee
- Cap Gemini (case study)

Learning outcomes covered on the course

At the end of this course, students will be able to:

- Understand and master the whys and wherefores of Industrial Ecology;
- Discover an informed vision of Industrial Ecology through its differents dimensions (engineering tools: mapping of material and energy flows (Material Flow Analysis, MFA), Life Cycle Assessment (LCA), energy audit, industrial symbiosis; but also economic and legal stakes) thanks to complementary experts;
- Apply Industrial Ecology on a industrial case.

Description of the skills acquired at the end of the course

C1 Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2 Develop in-depth skills in an engineering field and a family of professions
C3 Act, undertake, innovate in a scientific and technological environment
C4 Have a sense of value creation for his company and his customers
C9 Think and act as an ethical, responsible, and honest engineer, taking into account the environmental, social, and societal dimensions

3GS3185 – The principles of failures – Why complex systems fail and how to control the risk

Instructors : **Zhiguo ZENG, François CLUZEL, Marija JANKOVIC**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

It was a quite evening on 6 July 1988. Under the beautiful sunset of the North Sea, 228 workers began boarding the gigantic offshore oil drilling platform, the Piper Alpha, and started their routine night shift of working. It seems to be just another causal day. The then largest offshore platform of the UK kept producing oil and gas smoothly and quietly, until roars and flames from a huge explosion broke the serenity of the night and devoured everything. The platform was destroyed completely and, 167 out of the 228 workers, did not return from their last work. The tragedy shocked the entire world, as modern offshore oil platforms like Piper Alpha have been designed with a large number of safety systems connected in a “defensive-in-depth” manner: such accidents could occur only when all these safety systems fail, which is considered to be highly unlikely, if not impossible at all.

Sadly, severe failures like this keep occurring in almost every sectors of modern society. The nuclear accidents in Fukushima in 2011, the financial crisis in 2008, the explosion of the space shuttle Columbia in 2003… We can easily go on with this list. These sophisticated human-made systems, although all designed with seemly “unbeatable” safety systems, turned out to be much vulnerable than expected. They do fail and cause substantial damages and losses. What exactly caused their failures, then? Why do the seemly well-designed systems become vulnerable? Can we find some common rules governing these failures? If yes, how can we make use of this knowledge to manage the risks and make our systems safe and resilient? In this course, we attempt to give preliminary answers to these questions.

Quarter number
SG11

Prerequisites (in terms of CS courses)
None prerequisite

Syllabus

The course comprises 6 lectures of 3h :

Lecture 1 : A disappeared plane : How complex interaction makes systems fail.

- AF447 crash: Presentation and analysis.
- History and background of Normal Accident Theory.
- Introduction of complex interactions.
- Difference between complex and linear interactions.
- Example: Three-mile island accident.
- Example: Covid pandemic.
- Example: Boeing 737 max accidents.
- TD: Identifying potential complex interaction by intuitions.

Lecture 2: Great recession: How tight coupling makes systems fail. Great recession: Presentation and analysis.

- Introduction of tight coupling.

- Difference between tight and loose coupling.
- Example: Global supply chain disruptions.
- Example: Stability of European Union and Euro zone.
- Measuring failure propensity through normal accident theory.
- TD: Measuring the failure propensity of complex systems.

Lecture 3: Magic table and fancy diagram: How FMEA and FTA help identify potential risks.

- Introduce FMEA.
- Introduce FTA.
- Integration of FMEA and FTA.
- Managing the complexity of FMEA and FTA.
- Example: The AF447 accident revisit.
- TD: Application of FMEA and FTA.

Lecture 4: A raging pandemic: Why humans tend to make bad decisions regarding complex systems.

- Serious game: Controlling a pandemic.
- Elements of complex decision making problem.
- Typical troublesome decision-making behaviors.
- Phycological backgrounds of the troublesome behaviors.
- TD: Analyze your own decision-making behaviors.

Lecture 5: A mindful organization: How high reliability theory helps build alleviate human factors to failures.

- A crash that should not happen: ValuJet Flight 592.
- Introduction of human and organizational factors.
- High reliability organization theory.
- Example: Air traffic control system.
- TD: Application of the high reliability theory.

Lecture 6 : Evaluation through a course project.

- Find a real-world application to apply the theories discussed in this course.
- Some example:
- Analyze of failure/accident causes based on the theories presented.
- Identifying potential risks.Could be examples in your daily life, could also be examples from newspapers/tv/internet.

Lecture 1 to 5 are organized as follows:

2h : Lecturing : Introduce the main theories of the course.
1h: Practical section (TD) : Some practical problems/exercises will be worked out with the students.

Grading

There is no exam. The course will be evaluated by a project in which the students need to apply the learnt theory to solve a real-world problem and write a report.

Course support, bibliography

Textbooks:

- Lecture and reading materials from the lecturer.
- Clearfield, C. and A. Tilcsik (2018). Meltdown: Why our systems fail and what we can do about it, Penguin.
- Perrow, C. (2011). Normal accidents: Living with high risk technologies-Updated edition, Princeton university press.
- Domer, D. (1996). "The logic of failure: Why things go wrong and what we can do to make them right." New York Metropolitan.

Resources

- Equipe enseignante (noms des enseignants des cours magistraux) : Anne Barros, Yiping Fang, Zhiguo Zeng
- Taille des TD (par défaut 35 élèves) : NA

- Outils logiciels et nombre de licence nécessaire : non
- Salles de TP (département et capacité d'accueil) : non

Learning outcomes covered on the course

This course aims at giving the students basic knowledge on why human-made systems fail and how to manage the risks so that they can be operated safely and reliably. More specifically, the contents of this course include:

- general theories of why systems fail (e.g., Normal Accident Theory, the logic of failures)
- common failure causes and mechanisms;
- risk sources identification (e.g., FMEA, stochastic model checking);
- risk mitigation and control (e.g., high reliability organization, HAZOP);
- applying the theoretical methods to solve a real-world problem (through a course project).

Description of the skills acquired at the end of the course

C1 Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2 Develop in-depth skills in an engineering field and a family of professions
C5 Evolve and act in an international, intercultural, and diverse environment

3GS3500 – Project GSI DS

Instructors : **François CLUZEL, Marija JANKOVIC**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

The project "mention Design & System Sciences" is a long-term project (from October to April), in groups composed by 4 to 6 students. It is not a school project but a first professional mission, based on a real relationship between a client (company providing the subject) and a supplier (the group of students). The clients will be either partners of the "mention" (in priority), either other partners selected by the teachers. The students will work one to two days a week on the project et will probably have the opportunity to visit the clients. The students will mainly be in close interaction with their client. One to two teachers will also be assigned to each groupe to help the students.

Quarter number
SD9, SG10, SG11

Prerequisites (in terms of CS courses)
None

Syllabus
Project subjects will be released in September.

Class components (lecture, labs, etc.)
Project in mode "client-supplier"

Grading
The following criteria will be used for the final oral defense:

- Quality of the results for the client
- Ease of exploitation of the deliverables
- Quality of the students' behaviour assessed by the client and teachers
- Quality of presentation
- Respect of deadlines:
  - Deliverables
  - Presentations
  - Mandatory apointments

Resources

- 6 to 7 project subjects provided by industrial partners
- Tutoring teachers

Learning outcomes covered on the course
A the end of this activity, the students will be able to:

- Manage an industrial project in a professional way;
- Reformulate the needs of a client and implement an adapted engineering approach
- Manager a relationship "client-supplier"

Description of the skills acquired at the end of the course

C1. Analyse, design and implement complex systems made up of scientific, technological, social and economic dimensions.
C4. Create value for companies and clients
C7. Strengthen the Art of Persuasion
C8. Lead a team, manage a project

3GS4011 – Opérations & Supply Chain

Instructors : **Evren SAHIN, Bruno Croizat**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

The course aims to detail the main processes of Supply Chain management, and in particular those related to the planning of Value Chain activities.
The objectives of the course are:
Identify the issues related to demand forecasting, in connection with the company's management processes
Appropriate the collaborative forecasting process to obtain a consensus between the various actors concerned
Understand the different levels of business planning according to time horizons, from the strategic plan to the operational planning of supplies, production and distribution of finished products
Integrate the challenges, activities and stages of the Sales & Operations Planning (S&OP) process as well as the role of the different actors
Know the principles of customer relationship management in an end-to-end Supply Chain vision, and integrate the operational activities of the Order To Cash process

Quarter number

SG10

Prerequisites (in terms of CS courses)

N/A

Syllabus

Forecast To Stock - Demand Planning

- Challenges of demand forecasting in the company
- The different demand forecasting needs
- The quality of forecasts: Performance indicators
- The monthly collaborative process for developing the forecast
- The job of Demand Planner (skills and positioning in career paths)

Forecast To Stock - Supply Planning

- Business planning horizons and associated decisions
- Description of the S&OP process
- Best practices and key success factors of S&OP
- Process maturity levels (PIC, S&OP, IBP)
- Change management issues in the implementation of S&OP
- Principles for calculating the Production Master Plan (PDP), and associated process
- Principle of calculating component requirements (CBN-MRP) and supplier animation
- Principle for calculating the deployment of stocks of finished products (DRP)
- Scheduling of the production plan
- Synthesis, the MRPII model
- Information systems in support of Supply Planning
- The job of Demand Planner (skills and positioning in career paths)
- Product flow management provided by the Demand Planner/Supply Planner duo

Order To Cash – Customer Relationship Management

- The logistics services contract framing the Customer-Supplier relationship

- Animation of customer delivery performance and associated rituals
- Extended performance levers through collaborative actions
- The organization of the operational activities of the Order To Cash process
- Organization of Front Office and Back Office Client missions
- Customer Service jobs and interactions with other departments

Grading

Case studies (in groups)
Quiz (individual)

Resources

Courses and case studies

Learning outcomes covered on the course

At the end of this lesson, the student will be able to:

- Understand and implement the main sales forecasting methods
- Contribute operationally to the forecasting process
- Appropriate the principles and good practices in the use of planning tools and processes
- Be an actor and/or facilitator of the S&OP process
- Organize physical flows, information flows and financial flows of the Order To Cash process
- Understand the basics of customer relationship management

Description of the skills acquired at the end of the course

Main course competencies are: C1, C2, C3 and C4

3GS4020 – Management of industrial systems

Instructors : **CHRISTIAN MAISONNEUVE, Evren SAHIN**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Explore the fundamentals of technical, human and economic aspects of industrial management.
Discover the most powerful management levers and discern their systemic effects on the functioning of teams, the plant or the company and on the various components of performance, in the short, medium and long term.
The methods and tools are, for the most part, fairly easy to explain and understand. But it is always the understanding of their "managerial essence" (the coherence between technical, human and economic logics) that allows their harmonious integration into a common culture of performance. This is the most complete and difficult challenge of industrial management.
More than "knowing how to do it in a standard way", the objective is to "know how to identify the essential aspects of an industrial management situation and to be able to choose the levers that can be activated effectively".

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

- Define an industrial system
- Measure and manage industrial performance
- Understand and use performance management methods
- Define and deploy an industrial strategy
- Cultivate healthy social relationships
- Develop individual and collective skills
- Synthesis by sharing experience with 4 or 5 industrial leaders

Class components (lecture, labs, etc.)

Courses, illustrative examples and case studies

Grading

Continuous control - Quizz + Problem solving project provided by an industrial partner

Resources

Expert teaching team SCOM in Industrial Systems Management

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:
- Join the management of a production team in a personal and powerful way
- Consider the possible systemic effects of a managerial decision or practice
-Understand how a shift in production has a positive contribution to a career
-Clearly design the possible application of industrial management principles to the management of an entire company

-Validate their attraction to industrial professions

Description of the skills acquired at the end of the course

- Firmly grasp the manager's missions in an industrial function, his power and his limits
- Knowing how to identify the human, technical and economic components of a powerful and human management

- Be able to proactively integrate current managerial changes, in line with societal changes

CS compentencies validated: C1, C4, C5, C9

3GS4025 – Power BI application

Instructors : **Evren SAHIN**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Prerequisites (in terms of CS courses)

None

Description of the skills acquired at the end of the course

3GS4040 – Operational Excellence and Lean Management

Instructors : **Evren SAHIN, Camille Durr**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

- Discover the main continuous improvement/lean methodologies as well as the associated states of mind to improve the performance of a team / proces
- Create common knowledge for piloting systems by indicators
- To shed light on the key success factors and possible drifts of the approach thanks to examples
- Enable all participants to get started

Quarter number

SG10

Prerequisites (in terms of CS courses)

- Introduction to operations and supply chain management (IMOSC course)
- Management of industrial systems (MSI course)

Syllabus

- Introduction and history of Operational Excellence

- Presentation of what Operational Excellence is:

- Key success factors of an Operational Excellence approach and piloting by indicators
- Presentation of the 5 axes of the Lean manager
- Understand the performance facilitation rituals
- All actors of performance
- The main problem solving tools
- Some bonuses to go further

Class components (lecture, labs, etc.)

- Synthetic infographics
- Feedback videos
- Interactive exercises
- Puzzles and quizzes to validate the integration of key messages

Grading

Project the practice of different Lean Six Sigma tools in different environments (production & service)
Practice process improvement
Quizz, case study and project

Resources

Teaching team expert in Lean Management and Operational Excellence

Learning outcomes covered on the course

Ability to analyze an environment and propose improvement actions
Knowledge of the main Lean methodologies
Process improvement and load balancing

Description of the skills acquired at the end of the course

At the end of the course, the participant will be able to:

-Know the main Operational methodologies in Operational Excellence and Lean
-Improve a process by eliminating waste
-Conduct a breakthrough improvement project
-Know the daily tools to help a Manager deploy the Lean culture

CS competencies validated: C2, C4, C5, C9

3GS4050 – Purchasing, suppliers and subcontracting

Instructors : **Éric David, Jeremy GARANDET, Evren SAHIN**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **18,00**

Description

On average, a company's purchases account for two-thirds of its costs.
This enormous proportion, which has grown very rapidly over the past 20 years or so due to waves of outsourcing and globalization, has major impacts, not only financial, but also commercial and human.

This justifies a purchasing function that applies good practices and optimization methods, and offers interesting professional opportunities:

- To allow students who will take a position in purchasing to have a first vision of the purchasing function and process in order to be operational more quickly.

- Same objective for those who will have to work with purchasing (basically, the rest of the company).

- Finally, to enable future purchasing directors or future CEOs to have a better knowledge of purchasing to help them steer this function, in particular to set the purchasing strategy, objectives and know how to monitor and control.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Introduction to Operations Management and Supply Chain Management

Syllabus

- Purchasing issues, function, purchasing process, company performance and financial impact of purchasing, interfaces in the company (SupCh, production, mktg, R&D, legal, finance), work and career of the buyer, purchasing organization (people, physical means), major purchasing categories.

- Purchasing policy and strategy (link with the company's overall policy and strategy), make-or-buy, purchasing marketing, purchasing performance measurement and progress initiatives (by project and on an ongoing basis).

- Purchasing and supplier segmentation, standardization and differentiation of purchasing (what is purchased, how it is purchased, and standardization of tools - coding, classification, exchange mode, etc.).

- Legal and financial dimensions of purchasing, negotiation, contracts, disputes.Concepts of contract economics.Public procurement (principles). Purchasing risk management.

- Purchasing tools and technology: purchasing information systems (ERP, specific tools, EDI, EPOS/ VMI/ CPFR, e-business), impact of new digital and robotic technologies (big data, bock chain, artificial intelligence, RFID, cybersecurity, etc.).

- Presentation of group work and question and answer sessions

Class components (lecture, labs, etc.)

-Contexts and case studies from various industrial contexts
-Interactive exercises
-Feedback from experience

Grading

- Critical reading for presentation in group of students
- Diagnostic study of the purchasing function of a company in group

Resources

Course and case studies
TD size 30 to 35 students

Learning outcomes covered on the course

- To allow students who will take a position in purchasing to have a first vision of the purchasing function and process in order to be operational more quickly.

- Same objective for those who will have to work with purchasing (basically, the rest of the company).

- Finally, to enable future purchasing directors or future CEOs to have a better knowledge of purchasing to help them steer this function, in particular to set the purchasing strategy, objectives and to know how to monitor and control.

Description of the skills acquired at the end of the course

At the end of this teaching, the student will be able to validate compentencies C2,C4, C5 and C9

3GS4060 – Stochastic Models for Supply Chain & Operations

Instructors : **Oualid JOUINI**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **18,00**

Description

Queuing theory is an operational research discipline used to model, analyze and optimize operations. The objective of the course is first of all to appropriate basic methods for the analysis of stochastic models and queues. Then, several applications of modeling and quantitative analysis by queues will be presented. The applications concern the optimization and management of operations in manufacturing and service systems.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Basics in probability

Syllabus

Detailed course outline (content) :
- Introduction to stochastic processes
- Markov Chains
- Queues
- Applications in operations management
- Written test at the end of the course.

Grading

The evaluation consists of an individual written exam at the end of the course.

Resources

- CS teaching team
- TD Size: 35 students

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :
- Develop as intuitive an understanding as possible of the behaviour of stochastic systems.
- Master some basic tools for the analysis of these systems, namely Markov chains and queues.
- Model these systems in order to evaluate their performance.
- Apply these tools for operations management in production and service systems.

Description of the skills acquired at the end of the course

- Use and develop appropriate models, choose the right scale of modelling and relevant simplifying assumptions to address the problem
- Solve a problem with a practice of approximation, simulation and experimentation

CS competencies validated: C1, C2, C3 and C6

3GS4070 – Information Systems for Production, Supply Chain & Purchasing

Instructors : **Evren SAHIN**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

This course is designed to make students aware of :

- The importance of IS in the Supply Chain.
- The importance of building IS architecture to support the various links in the value chain.
- Business lines / Processes using information systems and how to choose the right system for your needs
- An overview of the leaders in information systems by typology
- Planning, operational monitoring
- The evolution of IS architectures and needs with new technologies

Quarter number

SG10

Prerequisites (in terms of CS courses)

All mandatory courses of the SCOM mention preceding this module

Syllabus

1 Introduction and key messages across the dimensions :
SC definition, SC models, major operational processes,
orga SC, IS stakes, IS architecture, economics & KSF IS projects

2 Focus on certain software classes
Supply Chain Planning (APS, DDMRP, Supply Control Tower)

3 Focus on certain software classes
Supply Chain Execution - OMS - WMS - TMS - collaboration platforms

4 Evolution of IS and new perspectives
new robotics and digital technology, link with cybersecurity,
computing power-storage-transmission, new architectures, etc.

Class components (lecture, labs, etc.)

-Case studies related to various industrial contexts
-Feedback from experience

Grading

- Case Study to be realised in group and all the associated deliverables
- Partcipation to the course

Resources

- Teaching staff expert in IS/IT applied to Operations & Supply Chain
- TD size: 30 to 35 students

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:

- Operationally contribute to the process of choosing IS and new supply chain technologies with a vision of the associated issues
- Appropriate the principles and best practices in the use of these tools
- Participate in the deployment or optimization of IS used in operations
- Provide orders of magnitude of the phases of project management of choice and implementation of an IS

Description of the skills acquired at the end of the course

- Knowledge of the main IS and the business lines and processes concerned
- To provide orders of magnitude for the project management phases of choice and implementation of an IS
- Openness towards new technologies that could transform the current vision of IS and CS architectures

CS competencies validated: C1, C4, C5, C6

3GS4075 – Applied Optimization

Instructors : **Denis Montaut**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

This course aims to:

- Present, analyze and characterize discrete optimization problems encountered in industrial and logistics systems by using mathematical programming approaches and tools
- Address these problems through the use of modeling and programming software

Prerequisites (in terms of CS courses)

Have some notions in optimization

Syllabus

Fundamentals of Optimization
Modeling and formulation of optimization problems
Use of a programming language and solvers for problem solving

Class components (lecture, labs, etc.)

- Case studies drawn from various industrial contexts
- Interactive exercises

Grading

Continuous assessment and project at the end of the course

Resources

Lectures and practical cases

Learning outcomes covered on the course

At the end of the course, the student will be able to:
- Know the main methodologies to address optimization problems encountered in industrial and logistics systems
- Formulate and develop a model adapted to the problem encountered
- Analyze the results and propose practical conclusions responding to the initial problem

Description of the skills acquired at the end of the course

Validated CS competencies: C1, C2, C6, C9

3GS4080 – Optimization methods and tools for Supply Chain and Operations

Instructors : **Evren SAHIN, Denis Montaut**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The objectives of this course are to:

- To enrich the conceptual baggage of students who already have notions of optimization and decision support,expanding the use of modeling tools for discrete system optimization
- Learn how to validate a problem analysis and modeling through a prototyping phase implementing programming tools (Python, Julia... for upstream data processing, exploitation of results),modeling and solving (commercial solvers Cplex, Xpress...)
- Enrich their practice by enabling them to carry out a realistic optimization project for decision support in an industrial context

Quarter number

SG11

Prerequisites (in terms of CS courses)

- basic knowledge in optimization
- mathematical programming and a modeling environment such as OPL/XPRESS IVE
- OA course followed

Syllabus

- Reminder of the fundamentals of the optimization approach, the main paradigms (PL, PM, PD, Heuristics...), positioning in the AI world; Introductory case flow
- Multi-criteria approaches in optimization : Pareto front, dominant solutions; Solving infeasible problems: goal programming
- Combinatorial optimization: construction of a weekly airline program
- Project (3 sessions, with theory reminders if needed, and coaching)

Class components (lecture, labs, etc.)

-Contexts and case studies from a variety of industrial contexts
-Exercises and feedback

Grading

The evaluation of this course will be based on a continuous knowledge assessment mark.
The exercises and case studies discussed in the classroom are given in pairs.

Resources

- Size : 30 to 35 students
- Software tools and number of licenses required: OPL Studio, Python (free software)

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:

- to recognize a situation of compromise
- to propose an adapted modeling tool
- to conduct a decision support project with a client and experts

Description of the skills acquired at the end of the course

t the end of the course, the student will be able to:

-Know the main methodologies to address optimization problems encountered in the supply chain
-Improve a process by formulating the desired compromises

-Conduct a process optimization project

Validated CS competencies: C1, C4, C6, C9

3GS4090 – Optimization for Complex Decisions

Instructors : **Adam ABDIN**
Department : **MENTION DESIGN AND SYSTEM SCIENCES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The objectives of this course are:

- Review of mathematical modelling, mathematical programming, important concepts of optimization (duality and convexity, simplex method, gradient methods, optimality conditions).
- Familiarize the students with optimization modelling software and commercial solvers.
- Illustrate the concepts taught in case studies related to industrial engineering, logistics, design science and control.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

1. Introduction and context
a. Model building in mathematical programming
b. Examples of most common problems in mathematical programming.
c. Fundamentals of optimization (linear programming, integer programming, nonlinear programming)

2. **Linear and Integer programming (going deeper)**
a. Duality and optimality conditions.
b. Optimality gaps and integer relaxation.
c. Sensitivity analysis
d. Available solvers and modelling languages

3. **Using programming language and commercial solvers**
a. Initiation to the use of software
b. Best practices in modelling in software
c. Understanding the output of a commercial solver
d. Industrial Intervention

4. **Multi-objective optimization**
a. Pareto front
b. Dominant solutions.
c. Solving multi-objective optimization problems (Weighted-Sum Method; epsilon-constraint method; TchebycheffMethod)

5. Sequential Decision Problems - Dynamic programming
a. Modeling sequential decision problems
b. Solving sequential decision problems (memorization, dynamic programming, Bellman equation)
c. Practical examples**.**

6. **Modelling situations of competition: game-theory problems**
a. An introduction to complementarity modeling
b. Application of complementarity modelling (transportation, energy, industrial competition)

Class components (lecture, labs, etc.)

- Case studies from a variety of industrial settings
- Interactive exercises

Grading

The assessment of prior learning will be carried out in continuous monitoring through the evaluation of practical cases discussed in the classroom and to be handed in after additional personal work. The grading will be based on the evaluation of practical student projects and report. The project will combine their knowledge in modeling and the use of software to solve a practical problem. The report should show their abilities to analyze the results and arrive at reasonable conclusions.

Course support, bibliography

Chong, E.K. and Zak, S.H., 2004. *An introduction to optimization*. John Wiley & Sons.
Chen, D.S., Batson, R.G. and Dang, Y., 2011. *Applied integer programming: modeling and solution*. John Wiley & Sons.
Williams, H.P., 2013. *Model building in mathematical programming*. John Wiley & Sons.
Bellman, R.E. and Dreyfus, S.E., 2015. Applied dynamic programming. In *Applied Dynamic Programming*. Princeton university press.

Resources

Course size: 45 to 50 students
Software tools and number of licenses required: OPL Studio, free software (Python, Julia, Pyomo); Solvers: (Cplex, Gurobi, GLPK, Ipopt)

Learning outcomes covered on the course

At the end of this course, the student will be able to:

- Recognize a decision situation that can be modelled by mathematical programming.
- Formulate and develop a proper model to address the decision problem.
- Use a commercial solver to solve the optimization problem.
- Analyze the results and propose useful managerial and engineering insights.

Description of the skills acquired at the end of the course

At the end of this course, students will be able to:

- Recognize a decision situation that can be modeled by mathematical programming.
- Formulate and develop a model adapted to the decision problem.
- Use a commercial solver to solve the optimization problem.
- Analyze results and propose practical management and engineering conclusions.

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3GS4091 – Retail Supply Chain Data Analytics

Instructors : **Evren SAHIN**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The course deals with the applications of Data Science & Business Analytics in the context of distribution and retail supply chain.

The main objectives are to:

- Develop an overview of Data Science & Business Analytics use cases applied to the retail sector
- Understand the different stages of product development
- Discover/re-discover the basic concepts of machine learning and apply them

Prerequisites (in terms of CS courses)

Have basic knowledge in Data Science/Data Analytics
Python 3

Syllabus

Develop a global vision of the retail sector, its players and its issues
Develop a global vision of different Data Science use cases applied to retail
Discover the macro-steps of building a product: from product discovery to adoption
Apply Data Science principles and build a first technical solution
Work as a team and organize themselves to work efficiently
Practice storytelling to present your approach and results

Grading

Evaluation of a Jupyter Notebook to validate the understanding of techniques in Data Science (Course 2)
Evaluation of a synthesis (3 slides) to validate the understanding of the different stages of construction of a product (Course 3)
Evaluation of a Jupyter Notebook to validate the use of techniques in Data Science in autonomy (Course 3)
Evaluation of the presentation of the case study (work + results + answer to the Business problem) (Course 4)

Resources

Expert teaching team SCOM
Industrial partners

Learning outcomes covered on the course

Be able to address the main issues of the retail industry, its actors as well as several IA use cases applied to retail
Be able to carry out the main stages of construction of a product
Be able to convert a business problem into a first technical solution
Apply a set of Data Science techniques (Data Cleansing, EDA, Model Selection, Model Training and Evaluation) using Jupyter Notebooks
Practice the art of storytelling to present your work/results + proposed response to the business problem

Description of the skills acquired at the end of the course

Be able to carry out the main stages of the building of a product
Know how to translate a complex problem into a data science problem to be solved
Propose innovative and realistic solutions

Know how to work in a team

CS competencies validated: C2, C4, C6, C9

3GS4210 – Flow control and stock management

Instructors : **Nicolas Vandeput, Evren SAHIN**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

The goal is for students to be able to manage the stocks of a supply chain both quantitatively (via models, equations and python simulations) and qualitatively. We will go over many inventory policies and the costs that need to be optimized.

The course will be punctuated by many questions asked about wooclap.
The course ends with a module on multi-level supply chain optimization. Most supply chains have not yet put it into practice and it can represent between 10 and 30% reduction in inventory.

Quarter number
SG11

Prerequisites (in terms of CS courses)

- Introduction to operations and supply chain management
- All other courses in the common core of the SCOM mention

Syllabus
Session 1 – Introduction- What is inventory optimization, what is an inventory policy
Session 2 - Inventory Policies
Session 3 – Costs framework
Session 4, 5, 6 – Quantitative optimization and Multi-Echelon supply chains

Class components (lecture, labs, etc.)

-Contexts and case studies from a variety of industrial settings
-Interactive exercises

Grading

Continuous control (wooclap): 45%
Simulation (personal work in Python): 20%
Business Game (groups of 4): 35%

Resources
Course and case studies

Learning outcomes covered on the course

-Optimize the stocks of a supply chain using equations
-Confirm the model by simulation
-Optimize the stocks of a multi-level supply chain
-Cite and explain all the costs that impact inventory management

-Cite, explain, and gauge the usefulness of all the lead times present in a supply chain
-Advise a supply chain on its E-2-E collaboration with customers and suppliers

Description of the skills acquired at the end of the course

* Be able to analyze the performance of the product flow in terms of customer satisfaction level and internal cost of Operations in the production of this service.
* To know and be able to intervene on the processes of inventory management

Validated CS competencies: C1, C2, C4, C6

3GS4220 – Distribution, e-commerce & logistics

Instructors : **Evren SAHIN**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Logistics plays a key role in many sectors of activity (industrial companies, distribution companies, service companies, ..)
This course aims to present the general principles of physical logistics in a distribution environment (warehouse or store)
The same principles can be applied in a production environment (plant)

Quarter number

SG10

Prerequisites (in terms of CS courses)

All compulsory courses of SCOM program

Syllabus

- Introduction to logistics in distribution, e-commerce and omnichannel
- (Visit of a logistics site)
- Warehouse functions and organisation: challenges, constraints, processes, tools
- Innovations in mechanisation, automation and robotisation
- Logistics challenges in e-commerce and omnichannel
- Restitution of case studies

Grading

Group project
Participation to the course

Resources

- Teaching CS team
- TD size: 35

Learning outcomes covered on the course

At the end of this course, the student will be able to:

- Know the operating principles of a warehouse and the main management methods
- Understand and analyse the functioning of an existing warehouse
- Understand the place of man in logistics
- Contribute operationally to the improvementperformance of a warehouse through the organisation of work, the physical organisation, the processes and means in place
- Understand the main types of mechanisation and their use cases

Description of the skills acquired at the end of the course

Validated skills :

- To know and be able to intervene operationally on the activities of a warehouse
- Understand the positioning and connections of warehouse management processes with the other major Supply Chain Management processes
- Be able to analyse the performance of the product flow in terms of customer satisfaction and internal cost of operations

CS competences validated: C2, C3, C4, C6

3GS4235 – Using the Cost to Serve Approach for Supply Chains

Instructors : **Evren SAHIN, Xavier Personnic**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Existing work on product cost price often underestimates the part related to the costs of logistical and administrative transport to product points of sale. The course therefore aims to address the CTS term of the formula: Landed Cost = Cost of goods sold (COGS) + Cost to serve (CTS).

This course will address:

- the scope and components of what Cost to Serve is
- the principles of its modeling and the possible evaluation methodology
- a "case study" on product distribution scenarios in West Africa (the choice of Africa is due to the fact that all the COST TO SERVE components are structuring favoring the illustration of the subject - the principles are applicable everywhere else too)
- the impacts of the Post COVID world on Cost to Serve

Quarter number

SG11

Prerequisites (in terms of CS courses)

All compulsory courses of SCOM program

Syllabus

- Introduction of the concept of "total landed cost" for manufacturers and the notion of COGS
- Definition of each component of an international distribution (upstream transport, logistics consolidation and export operations, main international transport, import operations, downstream transport to storage point, collection or customer delivery)
- Principles of modeling
- Presentation of the “XPELEC Africa” case study context and work on the case study
- Presentation of the consequences of the POST COVID world on Cost to Serve

Grading

Oral presentation written summary of students' responses to the 3 scenarios suggested for the case study

Description of the skills acquired at the end of the course

At the end of the course, the student will be able to understand:
- The place of Cost to Serve in supply chain cost analyses
- The Cost to Serve scenario analysis methodology

- Elements of strategy for doing business development in emerging countries

Validated CS competencies: C1, C3, C5, C7

3GS4240 – Simulation techniques for production systems

Instructors : **Oualid JOUINI**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **18,00**

Description

Presentation, general course objectives :

- To discover flow simulation in the field of production/logistics.
- Become aware that simulation is a powerful tool, provided that you know how to limit its use to cases that cannot be exploited by direct methods.
- Acquire a structured approach to modeling and simulation, based on the flow simulation software ARENA.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

- Introduction and initiation to ARENA.
- Assembly workshop
- Flexible Workshop - Call Centre
- Experimental design
- Final evaluation: Project support.

Grading

100% project and project support
Each group of 4/5 students will work on a project of analysis and optimization of a system of goods or services.
The tool that will be used is the ARENA software.
The project will be presented by the group of students at the end of the course.

Resources

Teaching staff
Software tools and number of licenses required: Arena software, free version.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

- Know how to analyze a system and judge whether or not it is worth using simulation.
- Identification of the key parameters of simulation and the use of experimental designs to identify the different scenarios to be simulated.
- Know how to validate and analyse the results of the simulation.

Description of the skills acquired at the end of the course

Validated skills :

- Use and develop the appropriate models, choose the right modeling scale and relevant simplifying assumptions to address the problem.
- Solve the problem with a practice of approximation, simulation and experimentation.
- Work in a team/collaboration

Validated CS competencies: C1, C2, C3, C6

3GS4250 – Hackathon Lean

Instructors : **Evren SAHIN**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Implementation of knowledge acquired in production systems management and operational excellence on real-life subjects in a situation encountered on an industrial site.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Industrial Systems Management Course (MSI)
Have basic knowledge on Lean & Operational Excellence

Syllabus

Travel to industrial site / Security, reception / Meeting with stakeholders
Visit of the industrial site / Brief of the subjects on which the students will work / Choice by students
Problem-solving workshops, Application of methodology on real cases presented
Intermediate Points
Final defense in front of the jury

Grading

Autonomous work with intermediate deliverables
Presentation of final results and defense

Learning outcomes covered on the course

Implement Lean Management principles & tools through a case study

Description of the skills acquired at the end of the course

Validated skills :
Management of production systems, factory integration, ability to understand a problem by listeningand questioning, use of continuous improvement tools and Lean approach.
CS competencies validated: C2, C4, C7, C8

3GS4260 – Supply Chain Case Study

Instructors : **Evren SAHIN, Jean-Marc Camelin, Caroline Leplatois**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **21,00**

Description

This module aims to deepen the themes and skills acquired in the courses related to other supply chain management.

- Students work in groups, through workshops.The work is done with a company that provides the topic to be handled.
- Each year the theme of the case study is revisited.
- The case study aims at illustrating the key role of what supply chain management plays / can play / must play (in its broadest understanding) in the success of the company and the transformation of their business model / strategy as well as in their operational management.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Have knowledge of fundamentals of Supply Chain Management

Syllabus

The case study takes place over one week.
The themes that it will address are related to supply chain issues.

Grading

Group workshops followed by a presentation before a jury.

Resources

Teaching staff of SCOM program
industrial partners involved in the case study
TD size: 35

Learning outcomes covered on the course

At the end of this teaching, the students will be able to handle a supply chain management related topic within the company

Description of the skills acquired at the end of the course

- Ability to understand a problem through listening and questioning
- Ability to conduct a case study and group work
- Ability to analyze a case study to highlight the potential for improved economicla, environmental and social issues through a transformation of the supply chain response.

Validated CS competencies: C2, C4, C7, C8

3GS4270 – Data Science for Supply Chain & Operations

Instructors : **Evren SAHIN**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **18,00**

Description

The objective is to teach students how to deal (in a business context) with a data science problem from start to finish, on a given issue by taking into account the important questions to be asked.
This course combines theory and practice and includes an introduction to AIthen addresses all the steps of a data science approach in a company, in the operations & supply chain management area.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

- introduction to AI (history, definition, principles...) and cases of use in companies
- dataset creation
- feature engineering and data cleaning
- creation of models with choice of evaluation metrics, validation strategy and feature selection
- production of models with covariate shift, security etc.
- project evaluation

Class components (lecture, labs, etc.)

-Contexts and case studies from various industrial contexts
-Feedback from experience

Grading

- Defense of project (treatment of a real data science problem) in front of a jury
- The students' ability to grasp the business problem and to associate a datascience issue will be assessed
- The ability to explain the whole approach precisely will also be taken into account

Resources

Software tools and number of licenses required: Python distribution (free)
TD size: 35
Public works rooms: 35

Learning outcomes covered on the course

At the end of this course, the student will be able to grasp the stakes of a problem corresponding to an operational issue and solve it by using data science.

Description of the skills acquired at the end of the course

- Understanding the different stages of a datascience problem
- Python development
- Understanding of the main methods of data analysis, the main algorithms and indicators for model evaluation
- Openness to the problems of putting models into production

Validated CS competencies: C1, C2, C4, C6

3GS4280 – Industry 4.0 & Digital Supply Chain

Instructors : **Alain Patchong**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **18,00**

Description

The objectives of the course can be summed up in three points:

- Understand the organizational and technical issues linked to robotization and the introduction of AI in industrial systems, in design and in the supply chain.
- Master the basic concepts, tools and methods applied to the design and management of production systems in the context of Industry 4.0.
- Understand the transformations introduced by new industrial practices, particularly at business model l evel.

Translated with www.DeepL.com/Translator (free version)

Quarter number

SG11

Prerequisites (in terms of CS courses)

Courses of mention in SD09 and SG10

Syllabus

Detailed Course Outline :
1. Introduction and Definition Industry 4.0
2. Innovation and impact on Industry 4.0: challenges or opportunities?
3. Industry 4.0 key technologies is the implementation modules
4. Product Development 4.0: The New Frontier of Competition
5. Manufacturing 4.0: towards greater efficiency
6. Supply Chain 4.0: boosting the value model
7. Implementation and organizational challenges
8. Factory visit
9. Group project defense

Grading

- Group projects " factory visit and proposal of an implementation roadmap "
- Course attendance

Tools that will be used to evaluate learning:
- Quizzes / Quizzes proposed at the end of each course / module will give immediate feedback and allow to reframe or return to concepts not understood.
- A project carried out in a group will allow students to be assessed in a "professional" environment: group work and application of concepts to a concrete case.

Resources

Teaching staff
Group size for visit: 20 students ideally, max. 24
Software tools and number of licenses required: Everything will be provided

Learning outcomes covered on the course

It will enable you to validate the 3 learning outcomes:

1 Understand the organizational, technical and managerial challenges associated with the digitization and robotization of industrial and logistics systems,

2 Master the basic concepts, tools and methods applied to the design and management of production systems in the context of Industry 4.0;

3 Visualize in the field the transformations introduced by new industrial practices

Description of the skills acquired at the end of the course

At the end of this teaching, the student will be able to
- Understand the organizational, technical and managerial issues associated with the digitalization and robotization of industrial and logistics systems.
- Master the basic concepts, tools and methods applied to the design and management of productive systems in the context of industry 4.0.
- Visualize in the field the transformations introduced by new industrial practices, particularly at the level of the business model.

Validated CS competencies: C2, C4, C6, C9

3GS4290 – Machine learning with applications to control, supply chain and design science

Instructors : **Guillaume Sandou**
Department : **MENTION CONTROL ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Machine learning is the scientific field that provides computers the ability to learn without being explicitly programmed. Machine learning lies at the heart of many real-world applications, including recommender systems, web search, computer vision, autonomous cars and robots.

The course will provide an overview of fundamental topics in machine learning that are used in the contexts of control of dynamical systems, supply chain and design science. Throughout the course, illustrative examples will be provided showing the strengths and the limitations of learning-based approaches.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Basic probability, statistics and linear algebra.
Some background in programming (e.g., Python, Matlab or any language of students' preference).

Syllabus

Overview of machine learning problems
Linear and logistic regression
Classifiers
Tree-based methods
Support vector machines (SVM)
Unsupervised methods
Deep Neural Networks (depending on the module progress)
Reinforcement learning (depending on the module progress)

Class components (lecture, labs, etc.)

Lectures : 18h
Tutorial : 18h
Tutorial : 6h

Procts to be carried out by the students

Grading

The evaluation of the course will be based on the two following required activites:

- Multiple Choice Questions : 30% of the final mark
- Project ; 70% of the final mark
Skill C1 will be evaluated during the exam and the projetc, skill C6 will be evaluated during the project

Course support, bibliography

- Shai Shalev-Shwartz and Shai Ben-David. Understanding Machine Learning: From Theory to Algorithms. Cambridge University Press, 2014.
- Christopher M. Bishop. Pattern Recognition and Machine Learning. Springer, 2011.
- Trevor Hastie, Robert Tibshirani, and Jerome Friedman. The Elements of Statistical Learning: Data Mining, Inference, and Prediction. Second Edition, Springer, 2017.
- I. Goodfellow, Y. Bengio et A. Courville. Deep learning. MIT Press, 2016.
- SUTTON, Richard S. et BARTO, Andrew G. Reinforcement learning: An introduction. MIT press, 2018.

Resources

Teaching staff: Guillaume Sandou (lectures and tutorials), Stpéhane Font, Pedro Rodriguez et Giorgio Valmorbida (tutorials)

Learning outcomes covered on the course

The course aims to introduce students to tools of machine learning used in the contexts of control of dynamical systems, supply chain and design science.

We expect that by the end of the course, the students will be able to:

- Identify problems that can be solved using machine learning techniques;
- Understand the mechanisms justifying the use of a particular method;
- Know the limits and possibilities offered by machine learning methods;
- Given a problem, identify and apply the most appropriate algorithms.

Description of the skills acquired at the end of the course

This module will give the opportunity to work and evaluate skills C1.2, C1.3, C6.1 and C6.3

3GS4300 – Equipment Performance

Instructors : **Christophe Gallon**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **18,00**

Description

The objective of this course is to :

- Understand the issues and principles of maintenance in the industry.
- To know the main strategies, the organization modes of the maintenance function and the associated resources.
- Discover the professions and possible careers for a CentraleSupélec engineer in the field of maintenance
- Understand the principles of reliability measurement, assessment and improvement methodologies.
- Understand the principles of optimizing equipment performance over its entire life cycle (from design to use)
- Learn how to improve the efficiency of maintenance by identifying value-added activities.
- Increasing the company's energy performance by translating societal issues into maintenance objectives and adapting equipment.
- Understand the value of participatory approaches involving maintenance and production department operational staff.
- To discover the (statistical) methods for controlling the conformity of products manufactured in factories and to successfully put a new product into production to meet customer expectations.

Quarter number

SG11

Prerequisites (in terms of CS courses)

- course Introduction to operations and supply chain management in SD9 from Dominant GSI
- all core courses of the SCOM designation

Syllabus

1 Presentation of the Total Productive Maintenance method:

- Issues, definition: participatory approach to improve facility performance
- Measuring equipment performance: synthetic rate of return, operational efficiency
- Improvement of working conditions
- The implementation of autonomous maintenance
- Maintenance from the point of view of a production manager

2 Maintenance issues, strategy and organization:

- Definition of the main themes: Reliability, Maintainability, Availability, MTBF, MTTR, Corrective maintenance (palliative-curative-improvement), Preventive maintenance (systematic-conditional- predictive- opportunistic), Operational safety,
- The challenges of the maintenance function
- The evolution of maintenance methods
- How to define a good maintenance strategy?
- How to implement a maintenance strategy?
- How to increase the company's energy performance?

3 Maintenance: from strategy to resource implementation:

- Management of maintenance costs - LCC approach (Life Cycle Cost)

- Self-maintenance (examples
- Improvement of the efficiency of scheduled maintenance (standardization, planning, capitalization, spare parts management)
- Safety of people and property
- Integration of experience feedback to design equipment

4 Reliability

- Definition: comparative, allocated, predictive reliability in design, operation, operational
- Objectives of reliability studies
- Link between reliability and maintenance
- Reliability assessment
- Methods for Safe Operation: Fault Trees
- OMF method: optimizing maintenance through reliability
- Examples of applications

5 elective activity

- Visit to maintenance facilities, testimony from a maintenance manager, interviews with maintenance professionals.

or

- Capability, quality control during industrialization, statistics applied to production

6 Evaluation

Written test then feedback in sub-groups: mapping of maintenance jobs and summary of the course's knowledge.

Grading

- In the final session of the course, students work on a written test to check understanding of the concepts and their application.
- During the last class session, the students, divided into sub-groups, build a map of maintenance jobs and synthesize, during an oral presentation, the main learning.

Learning outcomes covered on the course

- Vocabulary specific to equipment performance
- Methodologies used to increase equipment performance

Description of the skills acquired at the end of the course

- Think customer. Identify/analyse the needs, issues and constraints of other stakeholders, especially societal and socio-economic ones
- Have a background in a field or discipline related to the basic or engineering sciences
- Exploit any type of data, structured or not, including massive data

Validated CS competencies: C1, C3, C4, C9

3GS4310 – Prevision

Instructors : **Evren SAHIN, Nicolas Vandeput**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Demand Forecasting is an important step in business planning. To make a decision (fill a stock of components, buy a new machine, build a new factory, etc.), we need to estimate the demand. In this course, students will learn to use several quantitative and qualitative forecasting methods. They will also learn how to analyze demand history, measure forecast accuracy, and use statistical and machine learning methods to generate forecasts. Demand forecasting is only used to help other supply chain teams make good decisions. Metrics, processes, policies, cognitive biases, statistical methods, machine learning will be presented.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Python:

-You know how to load an excel sheet via Pandas
-You know how to create a function in python
-You know how to use a python foor loop
-You know Pandas / Numpy and know how to split / filter numpy arrays / pandas dataframes

Syllabus

-Introduction to forecasting: objectives, steps, and definitions
-The forecaster's toolbox: graphic summaries of a time series, measurement of precision
-Decomposition methods: classic, STL, strength of trend and seasonality
- Exponential smoothing methods: single, double
-Regression methods: machine learning algorithms

Class components (lecture, labs, etc.)

Courses, tutorials and student projects

Grading

Continuous assessment (theory, stat in excel, ML in python): 60%
Project (by teams): 40%

Course support, bibliography

-Hyndman, R. J., & Athanasopoulos, G. (2018). Forecasting: principles and practice. OTexts.
-Nahmias, S., & Olsen, T. L. (2015). Production and operations analysis. Waveland Press.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:

-Generate a forecast using statistical methods
-Generate a forecast using ML
-Optimize / define the granularity, temporality, metrics and the process to be used to forecaster the demand at best
-Explain the difference between demand, sales, budget, plan, targets
-Explain the Pro / con of several metrics
-Explain the risks of a forecast judgment and how to avoid them
-Explain how to avoid political problems during a forecast and what the symptoms are.
-Monitor and continuously improve a forecasting process by making it more efficient.
-Explain and advise on the methods to follow to collaborate E2E in the supply chain.

Description of the skills acquired at the end of the course

Graphical and statistical analysis of a demand history, calculation of forecasts, comparison between several methods
CS competencies validated: C1, C2, C4, C6

3GS4320 – Master Class Green Supply Chain & RSE

Instructors : **Isabelle Boccon-Gibod, Evren SAHIN**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

- Businesses are increasingly concerned by CSR issues (Corporate Social Responsibility)covering environmental, social and societal dimensions
in addition to a traditional economic and financial reading.
- Many companies are launching initiatives to improve their CSR performance.
- These initiatives may relate to a wide variety of aspects of a company's activity:
- The product in all these aspects(raw materials and components, semi-finished product, finished product)
- Packaging and product handling elements(internal packaging, external packaging, cardboard packaging, pallet,...)
- The choice and location of suppliers
- The production and processing of products
- Working conditions within the company as well asat its suppliers / subcontractors / service providers (logistics, transport,...)

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Detailed Course Outline :

- CSR issues and link with supply chain and operations management
- Urban logistics and environmental and social issues
- Evolution of upstream supply chains (supplier network and processing steps) to move towards "green value chains".
- Circular economy and supply chain 1 : the reverse supply chain of waste and material recycling
- Circular economy and supply chain 2 : repair business model, reuse, 2nd life of finished products and components
- Value placed on time and impact on the supply chain

Grading

Group project

Resources

Teaching staff
Stakeholders from the economic and social world
TD size: 35

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:

- Understanding the link between CSR issues and supply chains
- Understand the stakes of a global supply chain approach /scope to measure and improve environmental performance and social aspects of value chains
- To perceive the transformations in progress of companies operations , and in particularof their supply chain to move towards sustainable development.
- To understand how he/she can be actors of this transformationin the field of supply chain and operations management

Description of the skills acquired at the end of the course

- Understanding of CSR issues and their link with the supply chain
- Ability to analyze a case study to highlightthe potential for improved environmental performance and social issues through a transformation of the supply chain response.

Validated CS competencies: C1, C3, C4, C9

3GS4500 – Project concentration SCOM

Instructors : **Evren SAHIN**
Department : **MENTION SUPPLY CHAIN AND OPERATIONS MANAGEMENT (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

The SCOM "mention project" covers the entire academic period of the 3rd year (SD9 - SG10 - SG11, from October to April). The aim of this project is to apply the approaches, methods and tools developed in the SCOM program. The project is part of a professional framework, with a client (a company giving the subject) and a supplier (the group of students producing the deliverables). The clients are either partners of the mention (in priority), or other partners selected by professors. The students work one to two days a week on the project, on the campus or on the client's site.

Quarter number

SD9, SG10, SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Group project of 4 to 5 students

Class components (lecture, labs, etc.)

Project in group, with data and presentation of the context and the problem by the industrial partner

Grading

Project in groups of 4 to 5 students. Intermediate and final defense.

The following criteria will be used in the final presentation:
- Quality of the results provided to the client
- Ease of use of the deliverables provided
- Quality of the behaviour appreciated by the client and the teaching experts
- Quality of presentation
- Respect of deadlines: submission of documents, presentations, mandatory meetings

Resources

Projects proposed by companies sponsor of the SCOM mention, students and professors.

Learning outcomes covered on the course

At the end of this course, students will be able to:
- Professionally lead an industrial project
- Reformulate client's expectations and deploy an appropriate engineering approaches
- Manage a client-supplier relationship
- Summarize their results

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C2. Develop in-depth skills in a scientific or sectoral field and a family of professions
C3. Act, undertake, innovate in a scientific and technological environment
C4. Have a sense of value creation for his company and his customers
C7. Know how to convince
C8. Lead a project, a team
C9. Act as a responsible professional. Thinking, acting ethically

COMPUTER SCIENCE MAJOR (INFONUM)

3IF1005 – Participation in project management

Instructors : **Céline Hudelot**
Department : **DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **6**
On-site hours (HPE) : **6,00**

Description

Participation in the supervision of coding weeks

Quarter number

SD9

Prerequisites (in terms of CS courses)

Knowledge in programming

Syllabus

Participation in the supervision of coding weeks

Grading

Fail / pass

Learning outcomes covered on the course

Development and programming knowledge reinforcement
Coaching

Description of the skills acquired at the end of the course

C8: Demonstrate individual and team leadership on a complex project

3IF1010 – Advanced Algorithmics

Instructors : **Joanna Tomasik**
Department : **DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The objective of this course is to enrich the knowledge and reinforce the skills acquired in the Algorithmics and Complexity course offered to all freshmen.

It also aims to put students in the situation similar to that which is practiced during the recruitment process by major Internet players and renowned software companies - a programming competition: efficiency of algorithmic solutions, performance of the implementation, speed of programming.

Quarter number

SD9

Prerequisites (in terms of CS courses)

1CC1000 : Information systems and programming
1CC2000 : Algorithmics and Complexity

Syllabus

The course is divided into two blocks.
Titles of the block **Fine analysis of difficult problems**:

Lecture 1: Relationships between memory space and computing time
TD/TP 1: Exercises for Lecture 1
Lecture 2: Refining the P and NP problem classes (approximation and inapproximation)
TD/TP 2: Exercises for Lecture 2
Lecture 3: Refining the P and NP problem classes (parameterized complexity)

Titles of the block **Randomized algorithms, online algorithms**:

Lecture 1 : Randomized algorithms: Las Vegas and Monte Carlo
Lecture 2: Introduction to online algorithms: decision making with incomplete information and the competitive analysis
TD/TP 1: Exercises for Lectures 1 and 2
Lecture 3: Online Algorithms for Operating Systems: Resource Management; Yao's principle
TD/TP 2: Exercises for Lecture 3

The module will conclude with a three-hour feedback session following the competition in algorithm design and programming.

Class components (lecture, labs, etc.)

Each thematic block is organized in :

- three 1.5 hour lecture sessions presenting theoretical bases and main approaches to algorithm design,

- two 1.5 hour TD/TP sessions during which students, accompanied by a teacher, will study a panel of hard problems, analyze (or propose) their algorithmic solutions together with a study of their quality and implement them in python coding language.

Grading

Students will be confronted with optimization problems. Their task will be to:

- propose an algorithmic solution to solve it,
- calculate the complexity of the algorithm in time and in space,
- determine the guarantee on the quality of the solution their algorithm produces,
- implement the algorithm in python using the most suitable programming methods and data structures so that the execution time is as short as possible (in terms of processor time),
- a score will be a function of the theoretical quality of the algorithm, the manner of obtaining it and the efficiency of the program in python as well,
- the evaluation of the performance of the program will result from a competition launched on a numerical platform and will be calculated according to the automatized ranking,
- the results of this competition will be discussed during a three-hour feedback session.

Course support, bibliography

Bibliographical references on scientific articles will be given on the slides of the lectures concerned.

Resources

Lectures given by :

- Joanna TOMASIK (Joanna.Tomasik@centralesupelec.fr)
- Marc-Antoine WEISSER (Marc-Antoine.Weisser@centralesupelec.fr)

Practical classes supervised by :

- Johanne COHEN (Johanne.Cohen@centralesupelec.fr)
- Arpad RIMMEL (Arpad.Rimmel@centralesupelec.fr)
- Joanna TOMASIK (Joanna.Tomasik@centralesupelec.fr)
- Benoît VALIRON (Benoit.Valiron@centralesupelec.fr)
- Marc-Antoine WEISSER (Marc-Antoine.Weisser@centralesupelec.fr)

Programming in python. A digital platform to host a competition of implementations and to carry out their ranking.

Learning outcomes covered on the course

- fine analysis of hard problems: problems that can be solved in pseudo-polynomial time (weakly NP-hard problems), elements of the parameterized complexity (FTP), problems whose solution can be arbitrarily approached in time being a polynomial of the size of the problem and the inverse of the precision (FPTAS), problems that always remain difficult (strongly NP-hard problems)
- randomized algorithms and algorithms making decisions with incomplete information: randomized algorithms for solving difficult optimization problems (Las Vegas and Monte Carlo), online algorithms (deterministic and randomized), the competitive analysis evaluating their performance in the worst case, techniques for managing dynamic data structures and their quality, online algorithms used by operating systems
- the implementation of the algorithmic solutions proposed in programming language taking into account its quality in terms of memory consumption and execution time.

Description of the skills acquired at the end of the course

- to know theoretical approaches to determine the nature of a difficult optimization problem (problem classes: weak/strongly hard, FTP, FPTAS, APX) ; *la compétence C2.1 (Avoir approfondi un domaine ou une discipline relatifs aux sciences fondamentales ou aux sciences de l'ingénieur)*
- to know how to design randomized algorithms; *la compétence C2.1 (Avoir approfondi un domaine ou une discipline relatifs aux sciences fondamentales ou aux sciences de l'ingénieur)*

- to know how to make a decision with incomplete information by proposing online algorithms and to know how to determine the quality of the proposed algorithmic solutions (competitive analysis) ; *la compétence C2.1 (Avoir approfondi un domaine ou une discipline relatifs aux sciences fondamentales ou aux sciences de l'ingénieur)*
- to know advanced techniques of algorithm design ; *la compétence C6.4 (Résoudre des problèmes dans une démarche de pensée computationnelle)*
- to put into practice algorithms designed (the implementation in python) ; *la compétence C6.4 (Résoudre des problèmes dans une démarche de pensée computationnelle)*

3IF1015 – Responsible design

Instructors : **Anne-Laure LIGOZAT**
Department : **DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **10**
On-site hours (HPE) : **6,00**

Description

This course addresses the environmental impact of digital technologies. After a reminder of the environmental context, the impacts linked to the life cycle of digital equipment are first presented. Then the impacts, both positive and negative, that the digital sector can have on other sectors or on society as a whole are discussed. Finally, eco-design methodologies for digital services and infrastructures are detailed.

Grading

MCQ

3IF1020 – Advanced programming and software development tools

Instructors : **Dominique Marcadet**
Department : **DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **36,00**

Description

The objectives of this course are to present:

- the main concepts found in the various high-level programming languages, and their variations; a secondary objective is to learn the C and C ++ programming languages,
- system programming,
- current approaches to software development (DevOps, Software craftsmanship).

An important part is devoted to practice.

Quarter number

SD9

Prerequisites (in terms of CS courses)

- 1CC1000 : Information Systems and Programming
- 1CC2000 : Algorithmics and Complexity

Syllabus

- Concepts of programming languages
  - Introduction, overview of programming languages, modules and files
  - Imperative approach
  - Functional approach
  - Object approach
  - Generative approach
  - Complements
- System programming
  - Threads, process
  - Communication and synchronization mechanism
- Advanced development tools
  - DevOps
  - Continuous integration and deployment
  - Software craftsmanship

Class components (lecture, labs, etc.)

- Lectures: 12h00
- Tutorial classes: 3h00
- Practical work: 15h00
- Workshops: 6h00
- Personal work (exercises to be completed): 24h00

Grading

The exercises, started during practical work and finished with personal work, are evaluated and noted.

Course support, bibliography

- Books
  - The C++ Programming Language - Bjarne Stroustrup
  - Effective Modern C++: 42 Specific Ways to Improve Your Use of C++11 and C++14 - Scott Meyers
- Supports
  - Lectures slides with comments
  - Exercises to be carried out during practical work and personal work

Resources

This course consists of lectures to present the concepts, practical work allowing an operational appropriation of these concepts and workshops on the tooling and methodology aspects.

Learning outcomes covered on the course

At the end of this course, students will be able to:

- write correct and efficient programs in C and C ++;
- quickly learn a new programming language;
- use in a program the possibilities offered by an operating system;
- apply modern approaches of software development.

Description of the skills acquired at the end of the course

C1.4: Design: specify, implement and validate all or part of a complex system

- Specify, design, build and test complex software

C2.1: Deepen a field of engineering sciences or a scientific discipline

- Knowledge of the main concepts of programming languages
- Correct use of operating system services

C6.2: Design software

- Improvement of skills

3IF1030 – Law, ethics and privacy

Instructors : **Laurent Cabaret, Jean-Francois Lalande**
Department : **DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

This course aims to provide future engineers with the tools needed to apprehend the legal and ethical issues most meaningful in the digital world. Indeed, a professional in computing cannot do without a fine-grained understanding of the penal limitations of computing activities, or a fitting reasoning process regarding intellectual property, personal data protection or the interaction between the concept of responsibility and the possibilities offered by the modern artificial intelligence tools. While part of this reasoning is purely legal in nature, it is not uncommon to meet situations well-regulated, yet still raising moral questions, for instance about the social role of digital systems designers or their responsibility regarding their product, its uses and its impact. This course will allow future engineers to face this kind of ethical questioning with method.

Quarter number

SD9

Prerequisites (in terms of CS courses)

- Second year courses:
- Law.

Syllabus

- Lecture 1 (3h): Software and intellectual property
- Lecture 2 (3h): Information security law
- Lecture 3 (3h): Data law and AI law
- Lecture 4 (3h): Ethical reasoning in computing

Class components (lecture, labs, etc.)

Lectures : 12h

Grading

Not applicable.

Resources

Teachers:

- Jérémy Bensoussan, engineer and lawyer (Lexing Alain Bensoussan avocats)
- Virginie Bensoussan-Brulé, lawyer (Lexing Alain Bensoussan avocats)
- Marie Soulez, lawyer (Lexing Alain Bensoussan avocats)

Learning outcomes covered on the course

At the end of this course, students will be able to:

- Identify the legal risks related to a digital project;
- Design an intellectual property management strategy;
- Incorporate legal constraints into projects involving personal data;
- Identify the ethical issues raised by a project, and adress them with method.

Description of the skills acquired at the end of the course

C1 - Analyse, design and implement complex systems made up of scientific, technological, social and economic dimension
C2 - Acquire and broaden thorough expertise in an area of scientific and academic knowledge, as well as applied professional areas.
C6 - Advance and innovate in the digital world
C9 - Think and act as an accountable ethical professional

3IF1050 – Logics and Formal Systems

Instructors : **Marc Aiguier**
Department : **DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Presentation of the fundamental principles and formal tools (i.e. mathematically based) at the basis of all the methods of design, verification and implementation of computer systems. Thus, in this course, the fundamental notions of mathematical logic and automatic demonstration at the base of all these techniques of modeling and verification of computer systems will then be tackled. It will thus be presented classical logical formalisms such as 1st order logic but also non-classical ones such as modal logics widely used in the modeling of multi-agent systems and data representation.

Quarter number

SD9

Syllabus

In this course, we will adress:

1. Propositional logic
   1.1 Reminder of syntax, semantics and basic results (compacity, NP-completeness)
   1.2 Calculus (à la Hilbert, sequent, méthode des tableaux)

2. First-order logic
   2.1 Syntax, sémantics et basic results (Herbrand, indecidability, Loweinem/Skolem,etc.)
   2.2 Calculus (à la Hilbert and completeness proof, sequent and cut elimination, resolution)
   2.3 TP/TD with use of Coq system.

3. Modal Logic
   3.1 Syntax, semantics and basic results (Finite model theorem and decidability, bissimulation et co-induction, Van Benthem's theorem)
   3.2 Calculus (à la Hilbert, sequent and méthodes des tableaux)
   3.3 Modeling of data streams - Mealy's automatas and mu-calculus

Class components (lecture, labs, etc.)

This is essentially a theoretical course which will consist exclusively of lectures and application pcs. A TP / TD session is planned with the use of the Coq proof system.

Grading

Written exam (3h) and TP rated.

Resources

A course handout will be provided. Moreover, pc statements and their correction will be also provided.

Learning outcomes covered on the course

Knowing how to model and reason to strengthen the quality of systems.

Description of the skills acquired at the end of the course

Knowing how to approach the modeling of a given problem with a view to its computer implementation (decidable problem), and having understood the fundamental formal tools to study this problem either by computer simulation (symbolic evaluation, algebraic rewriting), or by analysing its implementation independently of any execution (automatic demonstration).

3IF1060 – Languages and Automata

Instructors : **Pascale Le Gall**
Department : **DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

Formal languages, as sets of words, are involved in many computer science disciplinary fields: word processing, programming language tools, theoretical computer science, complexity theory. The course is an introduction to the main classes of languages to which different models are associated (finite automata, grammars, Turing machines). We will see that these models allow us to reason about these classes of languages, differentiating them or equipping them with dedicated algorithms.

Quarter number

SD9

Syllabus

Formal languages

Regular languages
- Rational Expressions
- Finite automata
- Operations on automata: completion, minimization
- Kleene Theorem

Algebraic languages
- Grammars
- Derivation trees
- pushdown automata

Turing Machines
- Universal Turing Machines
- Undecidable problems
- Complexity classes

Application: lexical and syntactic analysis

Class components (lecture, labs, etc.)

By default, lectures and TD sessions, TP of lexical and syntactic analysis

Grading

Written examination

Course support, bibliography

A handout will be given to the students, as well as the subject and solutions for the TDs.

Description of the skills acquired at the end of the course

Automata, grammars and Turing machines are recognised as tools for modelling, abstraction and reasoning at the heart of the discipline of computer science.

Consequently, the skills targeted by the course are the following skills or sub-skills:

C1.2 Modelling: using and developing appropriate models, choosing the right scale for modelling and the relevant simplifying hypotheses
C1.3 Solve: solve a problem using approximation, simulation and experimentation
C2.1 Go deeper into an area of engineering science or a scientific discipline
C6 Be operational, responsible and innovative in the digital world

By default, they will be assessed during the written exam.

3IF1070 – Operating Systems

Instructors : **Idir Ait Sadoune, Frederic Tronel**
Department : **DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course aims to present the software architectures and the main concepts implemented in operating systems. Particular emphasis will be placed on the concepts of processes and threads, the mechanisms for managing parallelism, and memory management in a multitasking context. Shell programming in the Linux environment will allow the implementation of all the concepts discussed in this course.

At the end of this course, students will be able to understand how an operating system works, solve problems of competing processes management or threads sharing resources, understand how memory and filesystem work, and manipulate and program using the Unix/Linux shell.

Quarter number

SD9

Prerequisites (in terms of CS courses)

None

Syllabus

- 1 Presentation of the Operating Systems (1h30)
- 2 Process management, threads and synchronization (1h30)
- 3 - 4 TD - Process management, threads and synchronization (3h00)
- 5 Memory organization (1h30)
- 6 Memory management (1h30)
- 7 TD Memory Management (1h30)
- 8 File system (1h30)
- 9 - 10 Lab sessions File system under UNIX (3h00)
- 11 Introduction to Shell Programming (1h30)
- 12 TD Introduction to Shell Programming (1h30)
- 13 Process management under UNIX/Shell (1h30)
- 14 TD Process Management on UNIX/Shell (1h30)
- 15 - 16 Lab sessions Advanced Programming under UNIX/Shell (3h00)

Class components (lecture, labs, etc.)

- Lectures to introduce the concepts
- Lab sessions to implement the concepts

Grading

The grading of the course is based on continuous assessment

Course support, bibliography

- Silberschatz et al., 2004. Principes des systemes d'exploitation avec Java. Ed. Vuibert (2008)
- A. Silberschatz, P. Galvin, G. Gagne, Applied Operating System Concepts, John Wiley & Sons, 2002.
- Alain Cazes et Joëlle Delacroix, Architecture des ordinateurs et des systèmes informatiques, Edition Dunod, 2008.

Resources

The means implemented for this course combine lectures and Lab sessions favouring a concrete practice on the Linux operating system through the manipulation of the Shell.

Learning outcomes covered on the course

After attending this teaching unit, students will be able to:

- understand how a computer system works
- Resolve management problems of concurrent threads or processes sharing resources
- Understand how the memory works
- Understand how a file system works
- Manipulate and program using the Unix/Linux shell

Description of the skills acquired at the end of the course

C1.4 Design, detail and corroborate a whole or part of a complex system.
C2.1 Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.
C6.4 Solve problems through mastery of computational thinking skills.

3IF1080 – Risk and attack modeling

Instructors : **EDMOND DE ROFFIGNAC, Valerie Viet Triem Tong**
Department : **DOMINANTE - INFORMATIQUE ET NUMÉRIQUE**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

A cyber security risk analysis is about understanding, managing, controlling and mitigating cyber risk across a digital organization. Risk analysis a crucial part of data protection efforts.

Quarter number

SD9

Prerequisites (in terms of CS courses)

None

Syllabus

Threat analysis:

Threat overview, attacker's point of view. Threats on "classic" Information Systems. Threats on "industrial" Information Systems. Attacker's approach / Kill Chain reminders / concept of scenario, Sources and characterization of the threat, MITRE's references.

Methodological approach to risk analysis

Risk Assessment vs. Risk Management. Terminology (CID criteria / Dreaded events / impact analysis / Sensitive assets & support / vulnerability / vectors / ...), Introduction to EBIOS RM, Risk analysis referential.

Risk coverage and security measures

Security needs and security objectives, Security functions and measures, Anticipation / prevention / protection / detection / reaction, Continuous improvement approach, Security policy: Actors / roles and jobs related to security / Analyses / Architectures / Developers

Class components (lecture, labs, etc.)

Lectures and practical studies

Grading

Case study

Resources

This course gives the keys to build a relevant risk analysis.

Learning outcomes covered on the course

- assess and deal with the risks related to a digital project
- set up or strengthen a cyber risk management process
- communicate and justify the security choices made according to a risk analysis

Description of the skills acquired at the end of the course

C1 :Analyse, design and implement complex systems made up of scientific, technological, social and economic dimensions.

3IF1110 – Introduction to safety

Instructors : **Jean-Francois Lalande**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **15**
On-site hours (HPE) : **6,00**

Description

This course introduces the basic notions of security and safety in computer sciences, its ecosystem.

Quarter number

SD9

Prerequisites (in terms of CS courses)

No

Syllabus

CM 3h - Policies, security properties, security functions
CM 1.5h - Introduction to safety
CM 1.5h - Security ecosystem

Class components (lecture, labs, etc.)

Lecture

Grading

Face to face

Resources

Lecture

Learning outcomes covered on the course

- Know the fundamental properties and actors of the security
- Learn the vocabulary and the properties associated to the security and safety

Description of the skills acquired at the end of the course

None

3IF1120 – Intrusion detection

Instructors : **Pierre-François Gimenez**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **35**
On-site hours (HPE) : **18,00**

Description

Classical security approaches are preventive approaches that aim at stoping any violation of the security policy. Those approaches are necessary but not sufficient. Indeed, an attacker can exploit some vulnerability to circumvent preventive mechanisms. Reactive security consists in monitoring information systems to detect any violation of the security policy. The final goal is to react by applying countermeasures, sometimes automatically, to put the system in a clean state . This course presents the different classical approaches that can be used to detect intrusions in IDS (Intrusion Detection System) probes, the correlation of alerts raised by those probes in SIEM (Security Information and Event Manager), and the sharing of Cyber Threat Intelligence. It also presents security monitoring architectures that rely on such components to build a SOC (Security Operationnal Center).

Quarter number

SG10

Prerequisites (in terms of CS courses)

- Programing in Python (SIP)
- Computer Networking (elective course Network and Security)

Syllabus

- From security monitoring to incident response (lecture, 3h)
- IDS probe: Snort (lab, 3h)
- Cyber Threat Intelligence (lecture, 3h)
- Machine learning for intrusion detection (lecture, 3h)
- Use case (lecture, 1h30)
- Alert correlation (lecture, 1h30)
- SIEM (lab, 3h)

Class components (lecture, labs, etc.)

- Lectures (10h30)
- Lab (6h)
- Use case (1h30)

Grading

Labs are evaluated

Course support, bibliography

- Kruegel C., Valeur F., Vigna G. Intrusion detection and correlation: Challenges and solutions. Springer Advances in Information Security, Vol. 14, ISBN: 978-0-387-23398-7, 2005
- PDIS, Requirements reference, https://www.ssi.gouv.fr/uploads/2014/12/pdis_referentiel_v2.0_en.pdf

- Chris Sanders and Jason Smith. 2013. Applied Network Security Monitoring: Collection, Detection, and Analysis (1st. ed.). Syngress Publishing.

Resources

VirtualBox is used during the labs, which rely on open-source software (Snort, Suricata, Prelude)

Learning outcomes covered on the course

- Deploy and configure an Intrusion Detection System to detect intrusions
- Deploy and configure a SIEM for alert correlation

Description of the skills acquired at the end of the course

C2.1 Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.

3IF1130 – Content protection and privacy

Instructors : **Jean-Francois Lalande**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

In this course we present the rationale, stemming from intellectual property and personal data protection, behind the deployment of specific architectures and technical data protection techniques. The first part of the course explores classical and more advanced techniques for digital watermarking and multimedia content protection. We present usage control, violation detection and privacy protection requirements as complementary objectives. The second part focuses on privacy enhancing techniques, namely by the means of the protection of communications or privacy-preserving authorization techniques. Privacy by Design principles are presented, as well as the issue of privacy protection in databases, and differential privacy as a tool specifically tailored to this purpose.

Quarter number

SD9

Prerequisites (in terms of CS courses)

First year courses: Networks and Security

Syllabus

- Digital watermarking
- Content tracking
- Privacy-preserving data management and analysis

Class components (lecture, labs, etc.)

Lectures: 10h30
Lab sessions: 10h30

Grading

- terminal control 1h
- report of a project by pair

Resources

Teachers:

- Tristan Allard (Université de Rennes 1);
- Gaëtan Le Guelvouit (Institut B<>com).

Learning outcomes covered on the course

At the end of this course, students will be able to:

- Use the suitable mathematical and computational tools to watermark and track multimedia content;
- Design applications and information systems while following privacy by design principles;
- Analyse and evaluate the quality of a privacy or personal data protection mechanism.

Description of the skills acquired at the end of the course

C3: Act, engage, innovate within a scientific and technological environment

3IF1140 – Cryptography 1

Instructors : **Christophe Bidan**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Cryptography is a set of techniques that make it possible to ensure the security properties of a system, in particular the data confidentiality, the data integrity and the data authenticity. These techniques are based on mathematical foundations, but are implemented using algorithms (e.g. encryption and decryption primitives) and cryptographic protocols (how to carry out exchanges in a secure manner). This first part of the course is dedicated to foundation of modern cryptography, and cryptographic primitives.

Quarter number

SD9

Prerequisites (in terms of CS courses)

First year courses : SIP, Algorithms, Networks and security

Syllabus

This first part of 6 courses of 3 hours is dedicated to the fundamental concepts of modern cryptography and cryptographic primitives:
- Introduction: concepts, general principles, reduction to difficult problems, security models.
- Symmetric encryption (per stream and per block): RC4, DES, 3DES, AES
- Asymmetric encryption: RSA, El Gamal, elliptic curves
- Symmetrical Integrity, Hash Functions
- Signature
- Quantum and Cryptography

Class components (lecture, labs, etc.)

Lectures (18h)

Course support, bibliography

- Oded Goldreich. Foundations of Cryptography (2 volumes)
- N. Fergusson, B. Schneier. Cryptographie : Sécurité de l'information et des systèmes.

Resources

Teacher :
- Didier ALQUIE.

Learning outcomes covered on the course

At the end of this course, students will be able to :

- Evaluate the properties of the cryptographic primitives,
- Use appropriate cryptographic primitives according the required security properties.

Description of the skills acquired at the end of the course

C2.1 - Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.

3IF1141 – Competitive and distributed systems

Instructors : **Jean-Francois Lalande**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **40**
On-site hours (HPE) : **18,00**

Description

This course intends to discover theoritical and practical aspects of distributed systems.

The distributed systems are massively deployed in places where the infrastructure does not exist, or in wireless systems or with limited available energy. They are also used in systems where we want to avoid the use of a centrale authority. In such systems, the security properties that are enforced are multiple. It can be the the availability, integrity, no censorship, etc.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Algorithm and complexity
SIP

Syllabus

- Distributed system theory
  - Election algorithms, Byzantine generals
  - Consensus
  - Concurrency (sequential tasks, synchronization, Petri networks)
- Blockchain
  - Consensus
  - Proof of Work
  - Proof of Stake
- Bitcoin

Class components (lecture, labs, etc.)

12h lecture and 3h labs

Grading

Face to face

Resources

Lectures and labs.

Learning outcomes covered on the course

- Identify the distributed system that is adapted to a problem
- Understand the different types and properties of a blockchain
- Deploy a blockchain of type bitcoin

Description of the skills acquired at the end of the course

C3 - Act, engage, innovate within a scientific and technological environment

3IF1160 – Network and hardware security

Instructors : **Guillaume Hiet**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **36,00**

Description

The networking infrastructure is an essential component of any information system. To ensure the in-depth security of an organization as a whole, it is necessary to constantly control and supervise the architecture of the computer network, as well as the individual networking functions, in a fine-grained manner. This course aims to further the students' networking skills by focusing on security risks related to computer networks and on the deployment and configuration of the corresponding countermeasures. It will put a stress on a few particular aspects, like network access control, firewall configuration or the setting up of secure tunnels.

Quarter number

SD9

Prerequisites (in terms of CS courses)

First year courses: Networks and Security
Second year courses: Novel Networking Paradigms

Syllabus

Lecture 1 (3h): Introduction, architecture, supervision, regulatory context
Lab 1 (3h): Network access protection (802.1X, RADIUS)
Lab 2 (3h): IPsec
Lab 3 (3h): Operations within a SOC/NOC
Lecture 2 (3h): Advanced firewalls
Lab 4 (3h): Firewall configuration
Lecture 3 (3h): Wi-Fi security
Lecture 4 (3h): Routing security
Lecture 5 (3h): Introduction to hardware security mechanisms
Lecture 6 (3h): Microarchitectural attacks
Lab 5 (3h): Cache-based side-channel attacks
Lab 6 (3h): Enclaves

Class components (lecture, labs, etc.)

Lectures : 18h
Lab sessions: 18h

Grading

The module is evaluated through lab sessions (reports and defences).

Resources

Teachers:

- Guillaume Hiet (CentraleSupélec);
- Ruben Salvador (CentraleSupélec);
- Christophe Bidan (CentraleSupélec);
- Jean-François Calvez (Orange Cyberdefense).

Dedicated networking hardware will be provided for the lab sessions.

Learning outcomes covered on the course

At the end of this course, students will be able to:

- Design a computer network architecture providing good security properties;
- Configure networking equiments in compliance with ANSSI recommendations and with the General Security Database (RGS);
- Configure and maintain IPsec tunnels;
- Manage and supervise network access control;
- Anticipate and contain security risks related to radio communications and dynamic routing.
- Develop a cache-based side-channel attack
- Develop an application using an enclave mechanism

Description of the skills acquired at the end of the course

C2 - Analyse, design and implement complex systems made up ofscientific, technological, social and economic dimension

3IF1171 – Operating Systems

Instructors : **Pierre Wilke**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The objectives of this course are to give all knowledge required to develop a small but real kernel that is able to manage the process memory, the interruptions (and consequently the system calls), and is able to perform basic inputs-outputs.

Quarter number

SD9

Prerequisites (in terms of CS courses)

The prerequisites for this lecture are the following ones:
- Fluency in C language.
- Knowledge of RISC-V assembly language would be a plus.

Syllabus

The course is organised as follows:
I Lesson 1:
- Operating system history
II Lesson 2 :
- Operating system startup
- Control registers
- Priviledge levels
- Interrupt management
- System calls
III Lesson 3 :
- Process scheduling
- Scheduling algorithms
- Context switching
IV Lesson 4 :
- Synchronization primitives in kernel and user spaces
- Concurrency problems
- Pseudo-concurrency and real concurrency
V Lesson 5 :
- Virtual memory management
- Segmentation vs pagination
- Memory protection
- Binary loading
- Memory allocation algorithms

Class components (lecture, labs, etc.)

Lectures: 18h
Labs: 9h

Grading

Final exam: oral exam
Mandatory evaluations: Reports for two labs, including the code produced to answer the questions, and the number of functional tests passed by the code.

The oral exam accounts for 50% of the final grade, the lab reports account for the other 50%.

C2 validated by the validation of the whole module (NF >= 10)
C6 validated by the validation of labs (EO >= 10)
C7 validated by the performance at the oral exam

Course support, bibliography

- Andrew Tanenbaum, " Systèmes d'exploitation ", 3eme Edition, Pearson.
- Russinovich, Mark, Solomon, David, Ionescu, Alex, "Windows Internals", 6eme edition, Microsoft Press.
- Daniel Bovet, Marco Cesati, "Understanding the Linux Kernel", 2nd Edition, O'Reilly.
- Love, Robert , "Linux Kernel Development: A thorough guide to the design and implementation of the Linux kernel (Developer's Library) ", Addison-Wesley.

Resources

Teachers: Frédéric Tronel and Pierre Wilke
Hardware: PC equipped with a Linux operating system.
Software: GCC cross-compilation chain for RISC-V, qemu-riscv64 and docker (we provide an installation guide for these tools during the first lecture).

Learning outcomes covered on the course

Understand the concepts involved in the design of an operating system.
Understand the impact of services offered by an operating system on the performance and security of applications.

Description of the skills acquired at the end of the course

C2.1
C6.2
C7.1

3IF2020 – How computers work

Instructors : **Frederic Boulanger**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course presents the fundamental principles of how computers work and illustrates them through the design of a microprocessor, the translation of Python instructions into assembly language, I/O handling and interrupts. The microprocessor is designed under Logisim, I/O and interrupts are presented under MicroPython.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Python programming

Syllabus

CM1 and 2 (3HPE): Introduction, Computers, Processors
BE 1 (3HPE): Logic circuits, construction of the data path of a processor
CM2 and 3 (3HPE): Internal architecture of a processor, instruction set, execution
BE 2 (3HPE): Realization of a microprocessor under LogiSim
BE 3 (3HPE): Translation of Python instructions into machine language
CM4 and 5: Memories, inputs-outputs, interrupts
BE 4 (3HPE): Inputs-outputs, interrupts
BE 5 (3HPE): Device driver, abstraction of the hardware abstraction, relation with the operating system

Class components (lecture, labs, etc.)

- Website presenting the course material as well as elements for further study.
- Lectures to introduce the concepts
- Practical sessions with concrete achievements to implement the concepts and get familiar with them
- Use of a simulator for the design of the processor
- Use of a microcontroler+hardware component kit for the I/O and interrupts part

Grading

Continuous evaluation taking into account the involvement and the quality of the work produced during the practical sessions (as for a project).

Course support, bibliography

Andrew Tanenbaum, "Architecture de l'ordinateur", 4e édition, 2001

Andrew Tanenbaum, "Structured Computer Organization", 6e édition, 2012

John Hennessy, David Patterson, "Organisation et conception de l'ordinateur : The Hardware/Software Interface", 5e édition, 2013

John Hennessy, David Patterson, "Organisation et conception des ordinateurs : l'interface matériel/logiciel", 1994

John Hennessy, David Patterson, "Computer Architecture : A Quantitative Approach", 5e édition, 2011

Resources

This course combines lectures and practical sessions favouring a concrete practice on simulator for the design of a microprocessor, and on a microcontroller and hardware components for the study of the hardware-software interface. There are 15 HPE of practice for 9 HPE of courses.

Learning outcomes covered on the course

By the end of this course, students will be able to:
- analyze how a computer works and how it manipulates data,
- make more relevant choices in terms of computer architecture,
- design the software needed to operate a hardware component,
- determine the impact of programming language control structures on program execution.

Description of the skills acquired at the end of the course

C1.4 Specifying, designing, implementing and validating all or part of a complex system
- Define the architecture of a system at the interface between hardware and software
- Designing the software to operate a hardware component

C2.1 Deeper understanding of a domain in the fundamental or engineering sciences
- Knowledge of the mechanisms at play at the interface between hardware and software so that they can be taken into account in the design of systems as well as in the assessment of system vulnerabilities

C6.1 Solving a problem with a computational thinking approach
- Gain in competence in programming and modeling techniques

3IF2030 – Language processing

Instructors : **Benoit VALIRON**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **15,00**

Description

There are many languages used to structure information for computers. Of course, programming languages allow you to express programs, but we also use many languages adapted to specific domains (DSL, domain-specific languages). Knowing how to deal with languages is therefore an important issue in software development.
The objective is to present the main methods and techniques allowing the processing of various languages, that is to say their "comprehension" or their "modification" by the computer. This course therefore covers the fields of compilation, interpretation and transformation of languages.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Computer science shared curriculum

Syllabus

Concepts and algorithms. Language, syntax and semantics. Translators and interpreters. Grammars. Lexing. Parsing: top-down (backtracking, LL) and bottom-up (LR). Syntax-driven translation, abstract syntax trees (AST). Intermediate representation, optimization.

Tool study: generator of LL lexers and parsers

Project: design of a compiler

Class components (lecture, labs, etc.)

The course features both theory and practice: the theory presented in the course aims at supporting a fine understanding of the tools and techniques practiced in lab sessions.

Grading

The grading of the course is based on continuous assessment and a graded project.

Course support, bibliography

A. W. Appel. Modern Compiler Implementation in Java, Second Edition. Cambridge University Press, 2002.
A. Aho, M. Lam, R. Sethi, et J. Ullman. Compilateurs : principes, techniques et outils (2ème édition). Pearson Education, 2007.
T. Parr, The Definitive ANTLR Reference. The Pragmatic Bookshelf, 2007.

Resources

The course consists in 6 lectures of 1h30 and 6h of computer lab sessions.

Learning outcomes covered on the course

At the end of the course, the students will be able to

- Know and understand the different classes of parsers, their strengths and weaknesses.
- Design a parser for a specific set of semantics actions
- Build a compiler for a small language

Description of the skills acquired at the end of the course

Skill C2.1 : Avoir approfondi un domaine ou une discipline relatifs aux sciences fondamentales ou aux sciences de l'ingénieur
Skill C6.4 : Solve problems through mastery of computational thinking skills.

3IF2040 – Model engineering

Instructors : **Frederic Boulanger**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **15,00**

Description

Models are at the heart of system design, and computer models can themselves be seen as systems that are modeled, creating a hierarchy of models to which model engineering techniques are applied. This course discusses the role of models, the relationships between models, systems and languages in order to shed light on the foundations of model engineering and all the tools available to create metamodels, define model transformations, and validate models. These tools are used to limit redundancies, avoid inconsistencies and reuse the information encoded in the models in the best possible way. A mini-project under Eclipse EMF with QVT-operational and Acceleo takes place in parallel of the course, with a 3h practical session for follow-up. The course itself is composed of 4 sessions of 3 hours each. A last 3 hour session is dedicated to finishing the project and evaluating the work done by the students.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

- Slot 1:
  - Introduction, definitions
    - Systems, modele, modeling languages, metamodels
    - Typology of models
    - Handling complexity, Analysis and design
  - Semantics of models
    - The need for prceise semantics
    - Abstract and concrete syntaxes
    - Abstract and concrete semantics, models of computation
    - Principles for the definition of a semantics
    - Composition law for behaviors
- Slots 2, 3, and 4 (hands on, bring your computer):
  - Concepts :
    - eCore metamodels
    - Instantiation of a model
    - Generative approaches, semantics by translation
  - M2M model transformations, QVT operational
  - M2T model transformations, Acceleo
  - Design of a DSL for transition systems
  - Concrete use:
    - M2M transformation M2M toward a code-oriented model
    - M2T transformation to generate Java code
- Slot 5 (on your computer): Polishing the results of the project, evaluation and feedback

Class components (lecture, labs, etc.)

- Website presenting the course material as well as elements for further study.
- Lectures to introduce the concepts
- Practical sessions with concrete achievements to get familiar with the concepts.

Grading

The evaluation will take into account the quality of the work done during the pratical sessions, the project.

Course support, bibliography

https://wdi.centralesupelec.fr/mde/

Resources

This course combines lectures for the presentation of theoretical concepts, hands-on courses to understand the techniques, and personal work with some assistance during practical sessions in order for students to quickly get to grips with the various tools.

Learning outcomes covered on the course

By the end of this course, students will be able to :
- make relevant modeling choices based on modeling objectives,
- define a modeling language (a metamodel) adapted to a business problem,
- tool this language to make it usable (editor, parser, verifier)
- design transformations between different languages, both at the metamodel level and at the level of textual formats.
- They will also be aware of the problem of giving a meaning to a model, which will be deepened in the semantics course.

Description of the skills acquired at the end of the course

C1.2 Use and develop appropriate models, choose the right scale of modelling
to capture the phenomenon, choose the relevant simplifying assumptions
- Design a modeling language adapted to a business domain.
- Choosing the right level of abstraction to make the right compromise between expressiveness and ability to solve.

C1.4 Specify, design, build and validate all or part of a complex system
- Define the architecture of a design chain: choice of the different models involved and design of the transformations between these models.

C2.2 Import knowledge from other domains
- Mobilize skills as a generalist engineer in order to understand the client's needs in the design of a software system to model his business problems.

C3.3 Put new ideas at work, evaluate solutions, scale up to industrial processes to provide concrete results
- Know how to break down the design process into steps and create the different metamodels required, as well as the algorithms for validating and transforming the models between these steps.
- Create new modeling languages to allow the expression of new concepts, while relying on available engineering tools to limit the risk of failure.

C5.2 Listen to, understand and be understood by various audiences (training, trades,
cultures...) by using the appropriate means of communication.
- Accept and understand different business cultures, be attentive to differences in vocabulary in order to design modeling tools adapted to the client's needs.

3IF2050 – Static Analysis

Instructors : **Olivier Bouissou, Frederic Boulanger**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **9,00**

Description

Static analysis allows you to determine properties of a system by examining its models, without running or simulating it. It is an approach to verification that is automatic, but can report false positives (problems that do not actually exist) and ignore problems that are actually present (false negatives). This course aims to present the different techniques of static analysis, the areas where it is most relevant, its limitations and advantages in an industrial context.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

- CM 1: Introduction, nature and value of static analysis
- CM 2: Industrial constraints on static analysis
- Sessions 3 to 6: Case Studies

Class components (lecture, labs, etc.)

The methods used for this course are mainly case studies, with introductory lectures to introduce the concepts and industrial constraints that constrain the method.

Grading

The evaluation will be done in continuous monitoring on the participation in case studies and the quality of the renderings.

Resources

This course makes extensive use of industrial case studies to assess the possibilities but also the limitations of static analysis. Two lectures provide the initial knowledge required for the case studies.

Learning outcomes covered on the course

By the end of this course, students will be able to..:

- evaluate the relevance of static analysis for system verification,
- to choose a relevant static analysis tool in an industrial context,
- to interpret the results taking into account the defects of the method.

Description of the skills acquired at the end of the course

C1.4 Specify, design, build and validate all or part of a complex system

- Choose a verification technique adapted to the system to be verified and to the industrial environment.

C2.1 Have developed a field or discipline related to the basic or engineering sciences

- Knowledge of the advantages and limitations of static analysis in order to correctly assess the risk of errors in a system.

3IF2060 – Hybrid systems

Instructors : **Lina Ye**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **9,00**

Description

This course explores theoretical foundations and practical tools for the conception and verification of embedded softwares and systems, with a focus on the interaction between discrete and continuous aspects. Using an abstraction allows us to automatically verify some crucial properties. Verification of safety-critical embedded softwares and systems is a natural field of application of such techniques. A difficulty that arises is the necessity to take into account the interaction of the software with its physical environment. The second part of the course is devoted to presenting the current partial solutions of the analysis of such systems by leveraging the classical techniques such as model checking, statical analysis and testing.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

- CM1-TD1 : Introduction and modeling
  - continuous system, discrete system, hybrid system (embedded software)
  - hybrid automata (syntax and semantics)
  - simulations, zenos behaviors
- CM2-TD2 : verification of hybrid systems
  - motivation and problems
  - analysis of infinite systems
  - verification via model checking, statical analysis and testing.
- BE
  - Environment to model and verify hybrid systems (MATLAB & Simulink & Stateflow)

Class components (lecture, labs, etc.)

- Web site presenting the course material
- Lectures with exercise courses to introduce and present concepts
- Lab session to implement the concepts with concrete realization

Grading

The evaluation will be done in continuous control on the participation in the lab session and the quality of the reports.

Resources

wifi;
projector;
MATLAB & Simulink & Stateflow

Learning outcomes covered on the course

At the end of this course, students will be able to:

- design a software (discrete aspect) as well as the environment (continuous aspect) in which it will have to operate;
- know and understand the heterogeneity and interactions between models;
- choose the level of abstraction appropriate to the implementation of a hybrid system;
- know the current partiel solutions to verify the hybrid systems;
- understand the approach of model-based engineering and know how to use the tools for its implementation.

Description of the skills acquired at the end of the course

C1.1 Study a problem in its entirety, the situation as a whole. Identify, formulate and analyze a problem in its scientific, economic and human dimensions

- Identify the key elements for modeling hybrid systems, and formally capture them for analysis.

C1.3 Solve the problem with a practice of approximation, of simulation and of experimentation

- Understand the advantage of over-approximation for infinite systems as well as that of methods based on simulation.

C1.4 Specify, design, build and validate all or part of a complex system

- Specify the expected properties of the hybrid system taking into account the interaction between the discrete and continuous aspects.
- Build a model of this system with specifications.
- Partially check the properties on the model.

3IF2070 – Test

Instructors : **Lina Ye**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The test is a validation activity that allows a software to be compared to its specification. This course introduces the tester's job, the different testing techniques and how to implement them throughout the development process.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

12 slots of 1h30 (18 HPE): 6 classes (1h30), 3 design offices (3h)

- CM 1: Introduction, definitions
    - Activities of the validation engineer (Beizer classification...)
    - Different criteria and test types
    - Automation of test activity
    - Formalization of the test activity: introduction to coverage criteria
    - Limitations of the tests
- CM 2: Functional test
    - Random test
    - Data partitioning testing (equivalence classes, boundary tests, robustness tests...)
    - Unit testing (principle and implementation)
    - Fuzzing (principle and implementation)
- BE (slots 3 & 4)
    - Unit test environment (e.g. JUnit, PUnit)
    - Automatic test generation and data partitioning environment (e.g. JMLSpecs)
    - Fuzzing random test generation environment (e.g. OWASP WSFuzzer)
- CM 5 & 6: Structural test
    - Control and data graphs
    - Test by code coverage (criteria: block, decision, condition, MC/DC...)
    - Test by mutation (principle, levels and types of mutation)
- BE (slots 7 & 8)
    - Coverage test environment (e.g. emma, jcoverage, Simulink/Design Verifier)
    - Mutation test environment (e.g. PIT, Proteum)
- CM 9 & 10: Test by symbolic execution
    - Path predicates and constraint resolution
    - Static symbolic execution
    - Dynamic symbolic execution (concolic)
- BE (slots 11 & 12)
    - Symbolic and concolic execution environment (PathCrawler, CUTE, Angr, KLEE)

The remaining 12 HEEs are devoted to the finalization of the work carried out in design offices, as well as to revisions.

Grading

The evaluation will be done in continuous control on the quality of the work provided during the labs

Resources

Learning will be based on practice. After the lectures presenting the theoretical concepts and introducing the different tools, study labs will allow students to use different testing environments and work on concrete cases.

Learning outcomes covered on the course

- What is a test case? A system under test?
- Test design techniques:
    - black box techniques (partitioning, data coverage...);
    - white box techniques (code coverage, mutation...)
- Automatic test case generation:
    - Random testing;
    - symbolic execution;
    - concolic execution;
    - model-based generation

Description of the skills acquired at the end of the course

C6.3 Specify, design, build and validate software
- Testing is the most common validation activity.
- the test consists in comparing the specification to its final implementation

C2.5: Master the skills of one of the basic professions of the engineer
- train as a tester

C3.8: Know how to conceive, realize and move to industrialization.
- the transition to industrialization requires a major testing phase.

3IF2080 – Algorithms for distributed systems

Instructors : **Francesca Bugiotti**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **21,00**

Description

Many applications handle and store a big amount of data to generate effective and focused analysis.
In order to correctly handle those data and to correctly use the platforms it is necessary to understand how to develop software in distributed systems.

In this context the class illustrates how to treat heterogeneous, complex, and massive data using distributed methods, algorithms, and platforms.

Each optimization challenge and theory aspect will be analyzed with reference to a standard Big Data technology and a framework of reference such as Docker, Kubernetes, and Kubeflow.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Chapter 1. Introduction

- Concepts de distribution
- Modeles de distribution
- Service Architecture

Chapter 2. Data distribution

- Distributed and parallel algorithms

Chapitre 3. Environment for parallel programming

- Spark
- Docker
- Kubernetes
- Kubeflow

Chapitre 4. Comparison of multiple Cloud environments

- Analyse in detail the characteristics of different Cloud environments

Chapitre 5. Development of a project for the optimisation of a distributed application in collaboration with a company of reference.

Class components (lecture, labs, etc.)

Introduction. Lecture: 1,5h
Data Distribution. Lecture: 1,5h
Environments for parallel programming. Lecture: 3h
Advanced techniques for distributed analysis. Lecture: 3h
Comparison of Cloud environments. Lecture: 3h

14 slots of 1h30: 8 **lectures**, 1 **project presentation**, 4 **project implementation**, 1 **project discussion**.

Grading

The grading will be on the basis of the quality of the final project, on the results and the efforts shown during the development, and the final discussion.

Course support, bibliography

Managing Kubernetes: Operating Kubernetes Clusters in the Real World - Brendan Burns, Craig Tracey

Docker: Up & Running - Sean p. Kane, Karl Matthias

Learning outcomes covered on the course

At the end of this course, the students will acquire notions about:

- Data distribution
- Distributed Algorithms
- Tools for distributed computing
- Service Architecture
- Optimization of distributed computing
- Parallel algorithms for graphs
- Analysis of the distribution models of Hadoop, Docker, and Kubernetes.
- 8. Workflows and their application.

Moreover he will be involved in the development of a project for the optimisation of a distributed application in a real cloud environment in collaboration with a company of reference.

Description of the skills acquired at the end of the course

C2 Acquire and develop in-depth expertise in a scientific or sectorial field and/or job.

C6 Thrive and innovative in the digital world.

- C6.3 Specify, design, implement and validate complex software.
- C6.5 Operate any type of data, structured or not, including large ones. Understand their transmission.

C8 Lead a team, manage a project.

- C8.1 Work collaboratively in a team.

3IF2090 – Quantum programming for DL

Instructors : **Benoit VALIRON**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **21,00**

Description

Quantum computing is a computational model able to bring drastic changes in a wide spectrum of fields: high-performance computing, chemistry, cryptography, machine learning... This course presents what quantum computing is, its strengths and weaknesses and how a computer is programmed quantum. To serve as an illustration, we shall study Shor's factoring algorithm as well as some recent algorithms related to machine learning.

One should note that the course has a strong math flavor: quantum algorithms are based on algebraic properties of Hilbert spaces, and one of the goal of the course is to explain these.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Computer science shared curriculum ; Understanding of linear algebra. Prior knowledge of quantum mechanics is helpful, but not required.

Syllabus

- Model of quantum computation: mathematical notions
- Quantum Instruction Sets, quantum circuits and quantum programming
- Physical implementation, error correction
- Quantum subroutines, Shor's factoring algorithm
- Discussion on complexity gains
- Variational methods: VQE, QAOA.

Class components (lecture, labs, etc.)

The course is balanced between theory and practice: the theory presented in the course aims at supporting a fine understanding of the tools and techniques practiced in lab sessions.

Grading

The grading of the course is based on continuous assessment and a graded project.

Course support, bibliography

- Michael Nielsen and Isaac Chuang. Quantum Computation and Quantum Information: 10th Anniversary Edition. Cambridge University Press. 2010

- Peter Wittek. Quantum Machine Learning. Elsevier. 2014
- N. David Mermin. Quantum Computer Science: An Introduction. Cambridge University Press. 2004

Resources

The lectures incrementally present the concepts. Each concept is presented in a lecture with a theoretical part then implemented, on paper TDs and lab sessions on machine.

Learning outcomes covered on the course

At the end of this course, the students will be able to:

- Describe the differences between quantum and classical computation.
- Discern potential performance gains of quantum compared to classical algorithms.
- Assess the gains that quantum computation can bring to businesses
- Determine the resources required to run large quantum algorithms.

Description of the skills acquired at the end of the course

Skill C2.1 - Avoir approfondi un domaine ou une discipline relatifs aux sciences fondamentales ou aux sciences de l'ingénieur
Skill C6.4 : Solve problems through mastery of computational thinking skills.

3IF2211 – Logic and deductive systems

Instructors : **Benoit VALIRON**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

In this course, we will outline an important theoretical aspect for software science: modeling in a functional framework. On the one hand, we will study computational models based on rewriting, i.e. a general framework for evaluating a given algorithm or program. A particular focus will be put on the lambda-calculus. On the other hand, we will review three logical systems allowing to formalize logical theories and propositions: Dependent types, HOL and Hoare logic. The link between the two will be presented from the perspective of type systems.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Common curriculum in computer science

Syllabus

Computation: Universality, Church Turing's thesis, Computability, Halting problem; 1st order rewriting, Lambda-calculus, reduction strategy; Type systems, recursive types, dependent types; Type inference and compilation.

Logic: 1st and 2nd order, intuitionistic logic and classical logic; Curry-Howard equivalence; Expressiveness, decidability (ZFC, Presburger, etc); SAT/SMT.

Deductive systems: Structuring proofs; Inductive reasoning; Dependent types, HOL, Hoare logic

Class components (lecture, labs, etc.)

The course alternates between theory and practice, with the theory serving as a guideline for a detailed understanding of the processes at play in the tools and methods presented during lab sessions.

Grading

Continuous assessment and final project.

Course support, bibliography

- Pierce, B. C. (2002). *Types and programming languages*. MIT press.
- Appel, A. W. (2007). *Compiling with continuations*. Cambridge university press.
- Bertot, Y., & Castéran, P. (2015). Le coq'art (v8).
- Nipkow, T., & Klein, G. (2014). *Concrete semantics: with Isabelle/HOL*. Springer International Publishing.

Resources

The course is composed of 3 parts, each covering an average of 5 sessions of 1h30 (typically 3 lectures and 2 lab sessions). The coloring and weight of the different parts can change according to the needs.

Learning outcomes covered on the course

Upon completion of this course, students will be able to:

- Model a problem in a functional framework
- Know the major classes of logic systems and their relationships
- Characterize the correspondence between a logical system and a computational model through Curry-Howard

Description of the skills acquired at the end of the course

Competency C2.1 - Have furthered a field or discipline related to the basic or engineering sciences

Competency C6.4 - Solve problems using computational thinking

3IF2220 – Semantics and proof of programs

Instructors : **Frederic Boulanger**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **18,00**

Description

The value of a model lies in the meaning it carries and in the tools that can be applied to it. It is essential that the different tools interpret a given model in the same way. This course presents the semantic techniques that allow us to define the meaning of a language, and therefore the meaning of the models expressed in this language. We will see how to model the abstract syntax of a language (in connection with the language processing course), how to choose a semantic domain (usually logic), and how to establish a correspondence between syntactic elements and semantic elements. The different styles of semantics (operational, denotational, axiomatic) will be presented, as well as the relative consistency and completeness relationships. This course is based on the course on logic and deductive systems, and follows a pragmatic approach with a concrete implementation of concepts and methods in the Isabelle/HOL proof assistant. 16 hours of personal work are dedicated to getting familiar with the tool (tutorial to follow) and exercises. Two slots of 3 hours of face-to-face time are devoted to supervised practice (practical work) in order to anchor abstract concepts in their concrete implementation on a case study. Two other 3 hours slots are dedicated to the proof of C programs using Frama-C, in order to iluustrate how the techniques presented in this course are applied in an industrial context.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Logic and deductive systems course of the Software Science major

Syllabus

6 slots of 3h (18 HPE).

- Slot 1: Introduction
  - Need for a well defined semantics
  - Syntax and semantics
  - Operational, denotational and axiomatic semantics
  - Semantics and verification
  - Back to the Niklaus language
  - Higher order logics
  - Essential principles of Isabelle/HOL
  - Modeling the abstract syntax of Niklaus in Isabelle/HOL
  - Choice of the semantic domain
  - Mapping between the abstract syntax and the semantic domain
  - Semantics of Niklaus expressions
  - Elementary proofs (simplification of expressions and semantic equivalence)
- Slot 2: Operational semantics (hands on lecture)
  - An approach with functions, issue with the termination
  - An approach with inductive predicates
  - Small step and big step semantics
  - Big step semantics of Niklaus
- Slot 3: Denotational semantics (hands on)
  - On the meaning of recursive definitions
  - Example: the factorial
  - Higher order functions and fixed points

- Denotational semantics of Niklaus
- Slot 4: (hands on)
  - Axiomatic semantics of Niklaus
  - Proofs of programs
  - Weakest precondition
- Slots 5 and 6: Frama-C (Nikolaï Kosmatov)
  - Proof of C programs

Class components (lecture, labs, etc.)

- Website presenting the course material as well as introductory and in-depth material
- Self-training on the tools through a tutorial to be ready to follow the courses
- Lectures to introduce the concepts
- Hands-on course to implement the concepts with the assistance of a teacher
- Practical sessions with concrete achievements to implement the concepts and assimilate them

Grading

The evaluation is carried out through continuous control of the quality of the work done on exercises (the tutorial, among others), on the involvment in practical sessions, and on the final submited work.

Course support, bibliography

https://wdi.centralesupelec.fr/semantique/

Resources

This course relies on tutorials to get familiar with a problem and the tools used to solve it, lectures to define concepts, hands-on courses to implement them with the assistance of a teacher and practical sessions for a more autonomous practice. Personal work to complete what will have been started during the practical sessions is expected.

Learning outcomes covered on the course

By the end of this course, students will be able to..:
- to give a precise and formal meaning to a model,
- to choose the semantic approach adapted to the problem to be treated,
- to establish the basis for the definition of this semantics in a proof assistant,
- to rely on this semantics to check properties of a model or a program.

Description of the skills acquired at the end of the course

C1.2 Use and develop appropriate models, choose the right modeling scale
to capture the phenomenon, choose the relevant simplifying assumptions
- capture the essential elements of model semantics
- represent them in a manner appropriate to the problem at hand
- build several models at different levels of abstraction and link them together

C2.1 Deeper understanding of a domain in the fundamental or engineering sciences
- master logic as a modeling tool

C5.2 Listen to, understand and be understood by various audiences (training, trades,
cultures...) by using the appropriate means of communication.
- analyse with rigour the different meanings that a model can have, define the logical model that corresponds to what the users think.

C7.1 Convice about what matters. Be clear about the objectives and the expected results. Structure ideas and arguments
- clear up things thanks to formal logics
- avoid monolithic models, structure the different levels of abstraction.
- be explicit about the compromise between expressivity and solving capabilities

3IF2225 – Software engineering

Instructors : **Paolo Ballarini**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **15,00**

Description

The main objective of this course is to provide engineering students with an overview of the different approaches, techniques and methods used in the realization of critical (high impact on the economy, human life, ...) and large (mobilizing considerable resources) software. It should enable the learner to :

Understand what Software Engineering is and its objectives,
Know the different approaches to software development,
To perceive in a generic way the unified process and its characteristics,
Master the different sequences of activities of the unified process,
Implement the unified process in a project.

The course will focus on the Object Oriented Programming (OOP) paradigm as well as on the application of modelling formalisms such as UML class and sequence diagrams. Particular emphasis is placed on aspects such as reusability and adaptability of code through the application of design patterns.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Basics of software engineering and software quality.
software development models,
quality factors (external vs. internal),
principles and criteria of modularity,
Design cycles
V-cycle,
expression of requirements,
specification, implementation, verification, validation
Object-oriented programming paradigm
Programming languages as abstractions of machine code.
Evolution of abstraction. Notion of object (state and behaviour) and object type.
Computation as message exchange between objects.
Expression of problems in terms of objects.
Structure of OOP programs.
OOP as a natural paradigm for achieving software quality.
OOP in JAVA: classes and basic elements of the JAVA language.
Practices for software quality in OOP.
Code reuse.
Information hiding. Encapsulation.
Class composition vs. inheritance.
Inheritance related concepts: shadowing, overriding/hiding, polymorphism. Abstract classes. Interfaces.
Code testing and test-driven development (TDD).
Introduction and motivation: what are code tests and why are they useful.

Writing unit tests with Junit.
Introduction to test-driven development (TDD) methodology: from failing test units to passing test units.
UML class diagrams and sequence diagrams.
Role of modelling in OOP development.
Class diagrams. Relationships. Relationship annotations.
Generic association, aggregation, composition.
Relationships between classes: generalization, implementation.
Sequence diagrams: modelling the interactions of processes arranged in chronological order.
Design patterns.
Introduction and motivation.
The principle of opening and closing.
Families of patterns: creative, behavioural and structural design patterns.
Study and application of some design patterns.

Grading

The evaluation will be based on continuous assessment of the quality of the work done and the results of a mini-project with patterns.

Course support, bibliography

- "*Design Patterns: Elements of Reusable Object-Oriented Software".* Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides.
- *"Applying UML and Patterns: An Introduction to Object-Oriented Analysis and Design and Iterative Development". Craig Larman*

Resources

The means used for this course combine lectures and practical sessions to facilitate the assimilation of the concepts presented.

Learning outcomes covered on the course

On completion of this course, students will be able to:
- develop standard OOP solutions from a set of specifications/requirements,
- consider software quality aspects when designing a software solution,
- distinguish between design choices that result in more flexible solutions and those that result in code that is very expensive to extend.

Description of the skills acquired at the end of the course

C1.4 Specify, design, implement and validate all or part of a complex system

Define the structure of a software system
Design software taking into account its life cycle
C2.1 Have a deep understanding of a basic science or engineering field or discipline

Knowledge of standard software system modelling practices.
C6.4 Solve problems using computational thinking

Be able to model a software solution.

3IF2235 – Advanced programing

Instructors : **Dominique Marcadet**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **15,00**

Description

The objective of this course, which complements the "Advanced programming and software development tools" course, is twofold:
- to present an overview of the programming languages currently used with their main characteristics and areas of use,
- to understand why new programming languages are created on the basis of an example of a recent language,
- to present and implement some classical programming idioms in languages such as Java, C++ or Javascript.

Quarter number

SG11

Prerequisites (in terms of CS courses)

3IF1020: Advanced programming and software development tools

Syllabus

- Overview of programming languages
- Introduction of one of the last programming languages invented
- Programming idioms

Class components (lecture, labs, etc.)

This course is composed of lectures to present the concepts, tutorials to allow an operational appropriation of these concepts and graded practical work to validate the acquired skills.

Grading

The course is evaluated on the results of the practical work.

Course support, bibliography

Supports
- Lectures slides
- Exercises and solutions of small classes, statement of practical work

Learning outcomes covered on the course

At the end of this course, students will be able to:
- choose a programming language according to the constraints and context of a project,
- implement advanced programming techniques.

Description of the skills acquired at the end of the course

- C2.1: Deepen a field of engineering sciences or a scientific discipline
- C6.2: Design software

3IF2240 – Design methods and tools

Instructors : **Frederic Boulanger**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **12,00**

Description

This course aims to provide a culture of the design tools and methods used in the industry (agile development methods, continuous integration, design patterns).

It continues the introduction made in SD9 in the Programming Workshops and Development Tools course, and consists of a series of lectures and case studies given by industrialists throughout sequences 10 and 11. This course can be pooled with the Computer Systems Architecture course.
Examples of topics covered :

Agile at scale
SCRUM
Requirements engineering

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Interventions by industrialists on different themes, according to the opportunities and needs identified.

Class components (lecture, labs, etc.)

Interactive training, immersion in business processes, practice on case studies.

Grading

The evaluation will be done either directly on the participation and renderings during the interventions, or on the application of the methods presented to another issue (for example, application of a method to the project carried out during the year).

Resources

This course is composed of a series of interventions from industrialists. Interactivity is privileged, as well as team work on case studies.

Learning outcomes covered on the course

At the end of this course, students will be able to integrate themselves more quickly into the processes implemented in companies. They will also have a better vision of human and relational aspects and their impact on the use of methods and techniques in companies.

Description of the skills acquired at the end of the course

C8.1 Teamwork/Collaboration

C3.2 Chosing solutions and behaving in a pragmatic way, in order to obtain concrete results

C4.1 Identify/analyze needs, societal issues and the constraints of other stakeholders, especially the societal and socio-economic ones

3IF2250 – EventB

Instructors : **Idir Ait Sadoune**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **21,00**

Description

This course will allow students to discover the basic concepts of the B method through modelling and proof activities using Atelier B, the main IDE of the B method. The application of a Top-Down specification approach will allow students to use refinement, which is one of the basic operations of the B Method, and automatically generate C code that is verified and conforms to the initial specification. Animating B models using the ProB tool is also covered.

At the end of this course, students will be able to apply a complete critical software development process from specification to automatic source code generation.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Computer Science Shared curriculum

Syllabus

- C1-C2 (CM-TD): The B Language
    - Set theory
    - The 1st Order logic and the Hoare Logic.
    - Generalized substitutions and the Dijkstra weakest precondition.
- C3-C4 (CM-TD): The B Model
    - Modelling a system using the classical B-method
    - The refinement of a B system
- C5-C6 (CM-TD): The proof in B method
    - The proof obligations of a B Model
    - Interactive proof with Atelier-B
- C7-C8 (CM-TD): The checking model in B method
    - B-model animation with ProB
    - Viewing B models with BMotion
- C9-C10 (CM-TD): The implementation of a B model
    - Code generation by refinement
- C11-C14 (TP) : lab session on machine

Class components (lecture, labs, etc.)

- Lectures to introduce the concepts
- lab sessions to implement the concepts

Grading

The grading of the course is based on a graded project.

Course support, bibliography

- Jean-Raymond Abrial, The B-Book, Cambridge University Press, 1996
- https://www.clearsy.com/wp-content/uploads/sites/3/ressources/manrefb1.8.6.uk.pdf | B LANGUAGE REFERENCE MANUAL

Resources

The practices used in this course combine lectures and tutorials favouring a concrete practice on the existing tools around the B method.

Learning outcomes covered on the course

At the end of the course, students will be able to :

- model with the B-method.
- manipulate the notions of abstract machine and refinement.
- establish the proof of consistency of a B model and its refinement (with the prover of Atelier B).
- animate a B model (with the Pro-B model-checker).
- generate verified code from a B model
- develop critical software

Description of the skills acquired at the end of the course

- C1.4 Design, detail and corroborate a whole or part of a complex system.
- C2.1 Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.
- C6.4 Solve problems through mastery of computational thinking skills.

3IF2260 – SCADE and synchronous for critical systems

Instructors : **Frederic Boulanger**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **21,00**

Description

This course is an introduction to the synchronous approach and its formal environment.
It includes an important part of practice with the realization of an industrial case study with the SCADE suite:

- Advanced model-based design
- Simulation and debugging
- Testing and verification
- Automatic generation of certified code

This course calls upon speakers from the company ANSYS which develops the SCADE suite.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

14 slots of 1h30 (21 HPE): 2 lectures (3h), 2 hands-on courses (3h), 5 practical sessions dedicated to the project (15h) with defense.

- CMs 1 & 2: Introduction to the synchronous paradigm
  - Critical Software Development Context
  - Synchronous model: structure and time management
  - The Lustre Synchronous Language
  - operators
  - causality
- CM on machine (slots 3 & 4): Initiation to the SCADE synchronous programming environment through a concrete case study:
  - Synchronous model of Scade, flows and operators
  - Flow charts, automata...
  - Simulation
  - Scade Verification
  - property monitors
  - use of the evidence engine
  - testing and coverage
- CM/project (slots 5 to 14): Realization of a complete case study
  - Covering all stages of the development process from specification to certified code generation, including modeling, simulation, proof and testing...
  - The project will focus on a concrete application proposed by the industrial partner.
  - The students will be supervised in a classroom environment to help them learn how to use the SCADE suite.

Class components (lecture, labs, etc.)

Lectures on the theory in small quantities, lectures with very supervised practice for initiation, more autonomous practice for application to an industrial case.

Grading

The course will be evaluated according to the quality of the submited work and on the defense of the mini-project

Course support, bibliography

- https://www.ansys.com/blog/free-download-ansys-scade-student
- The Synchronous Languages 12 Years Later. Albert Benveniste, Paul Caspi, Stephen A. Edwards, Nicolas Halbwachs, Paul Le Guernic, and Robert de Simone. Proceedings of the IEEE 91(1):64-83, January 2003.
- Synchronous programming of reactive systems. Nicolas Halbwachs, Kluwer Academic. 1993.

Resources

This course combine lessons to get acquainted with the approach, and practice with SCADE suite, first on a simple example, then on a more significant case study.

Learning outcomes covered on the course

By the end of this course, students will be able to:

- evaluate the relevance of the synchronous approach to system design
- implement this approach in the SCADE suite
- specify the expected properties of the system, and verify them
- generate application code from the models.

Description of the skills acquired at the end of the course

C1.2 Use and develop appropriate models, choose the right scale of modelling and relevant simplifying assumptions to address the problem

- Identify the critical properties of a system, formulate a solution to ensure them
- Choose the synchronous reactive model where relevant
- Capturing the different aspects of the system in the synchronous paradigm

C1.4 Specify, design, build and validate all or part of a complex system

- Specify the expected properties of the system
- Build a model of this system
- Check the properties on the model and generate the certified code of the system.

C2.1 Have a background in a field or discipline related to the basic or engineering sciences.

- Deepening of the notions of time, simultaneity, parallelism.

3IF2270 – Real-time systems

Instructors : **Pascale Le Gall**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **21,00**

Description

This course focuses on the modeling, specification, validation and verification of Real-Time Systems (RTS). These are essentially reactive systems whose behaviors are subject to real-time constraints sometimes critical (embedded systems, protocols, web services, cyber-physical systems, ...). Real-time constraints are particularly difficult to state and guarantee when systems are concurrent or distributed, because these systems are highly non-deterministic, due to event interleaving, asynchronous communications, and quality of service defects (message losses, network latency).
Organization
1. Presentation of Real-Time Systems: hard/soft real-time, time constraints, modeling and simulation (e.g. DEVS Discrete Event System Specifications)

2. Timed Automata (Alur and Dill 1991) are the appropriate modelling formalism for such systems. They are based on the use of clocks, variables with positive or zero real values, in charge of modelling the time flow. These clocks can be reset to zero and conditioned to cross transitions. The UPPAAL tool (http://www.uppaal.org/) allows the analysis of timed properties using model-checking techniques.

3. Timed Input/Output Symbolic Transition Systems (TIOSTS) are useful for modeling reactive systems. They use clocks to model time and state variables to model data sent and received by (sub)systems. These systems can be analysed through symbolic execution techniques, useful both for validating the design by animating specifications and for verifying implementations through conformance testing (also called model-based) techniques. The DIVERSITY tool (https://projects.eclipse.org/projects/modeling.efm) is a symbolic execution platform for modeling and analyzing STRs specified by TIOSTS.

4. Case study (e.g. the "trickle" algorithm used for code update propagation in wireless networks): modeling and analysis using the UPPAAL and DIVERSITY tools.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

The course will be organized as follows:
- Lectures
- Tutorials on how to use software (UPPAAL, DIVERSITY) on pedagogical examples.
- Sessions dedicated to the realization of a personal project

Grading

Realization of a project (report, implementation, analysis, oral defense)

Course support, bibliography

Slides - Research papers

Resources

Research Articles
Course material (slides)
Software (UPPAAL, DIVERSITY) installed on students' personal labtops

3IF2500 – Project

Instructors : **Frederic Boulanger**
Department : **MENTION SCIENCES DU LOGICIEL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) :

Description

The third year project allows students to apply their skills in an industrial or research project with the corresponding business constraints. In particular, it allows them to discover the different facets of the professions they will be able to carry out. These are the projects of the "Computer and Digital" major, including "Computer Systems Architecture", "Cybersecurity", "Artificial Intelligence" and "Software Science".

The objectives of the project are

- The development of a "product" meeting the needs of a client (company, laboratory, association, students).
- The implementation of a rigorous methodology to go from the idea to the "product".
- The continuation of learning project management.
- Demonstrating the ability to present in writing and orally in a professional context.

Quarter number

SD9 SG10 SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Depending on the project. The projects can either be Dominant projects and thus cover themes developed in at least two of the dominant's mentions or they can be mention projects and thus address themes specific to one of the dominant's mentions.

Class components (lecture, labs, etc.)

Working in project mode.

Grading

The evaluation will be done by a mid-project point, and mainly by the final report, the final defense, and the opinion of the person in charge and client of the project. A jury, mobilized for the final defenses, will integrate these elements to evaluate the project as a whole.

Resources

- The projects take place in teams of 2 to 3 students.
- 200 hours are devoted to the projects.
- The supervision modalities depend on the type of project:
  - For CEI projects (industrial study contracts), supervision is shared between the industrialist and a teacher from the school who leads the students in their work.

    - For "Laboratories" projects proposed by a teacher, supervision is entirely provided by the teacher.
    - For all other types of projects (associations, partners, CPI), the supervision is mainly done by the person proposing the project (client), a teacher from the school ensuring the good progress of the project and the intermediate milestones.
- A mid-project point will be organised in December to ensure that the project is running smoothly.
- At the end of the project, a jury presentation will take place.

Learning outcomes covered on the course

By the end of the project, students will have learned :

- to work in teams outside the academic context
- to take into account the business constraints in the realization of a project
- manage uncertainty in the definition of expected results
- to present their project and results in a professional context

Description of the skills acquired at the end of the course

Working in teams outside the academic context is part of C8: "Leading a project, a team" and C5.2 "Listening, being understood and working with people from different cultures, backgrounds and skills".

Presenting one's project and results in a professional context is part of skill C7: "Knowing how to convince".

Taking business constraints into account in carrying out a project is part of C1: "Analysing, designing and building complex systems with scientific, technological, human and economic components", C2.3: "Identifying and rapidly acquiring the new knowledge and skills needed in the relevant fields, whether technical, economic or other", and C4: "Having a sense of value creation for one's company and one's customer".

Managing uncertainty in the definition of expected results is part of C3.4: "Making decisions in a partially known environment, managing the unexpected, knowing how to take risks" and C3.7: "Choosing solutions and acting pragmatically, with a view to obtaining tangible results".

Competencies C9: "Act as a responsible professional. Think, act ethically" and C6: "Be comfortable and innovative in the digital world" can also be mobilized.

3IF3020 – Deep Learning

Instructors : **Wassila Ouerdane, Herve Le Borgne**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **50**
On-site hours (HPE) : **30,00**

Description

The aim of this course is to familiarize students with the principles and methods of deep learning. This is a field in strong (re) growth for ten years, mainly because these artificial intelligence techniques have significantly improved the state of the art in several areas such as speech recognition, computer vision or decision making. computer aided. These successes have made them known beyond specialists, and their reputation has grown among the general public, journalists, political and economic decision-makers.

The course aims to give a theoretical and practical mastery of the basics of the field.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Students are expected to have a solid knowledge in linear algebra and statistics. They should be comfortable with a development environment, preferably under Linux or MacOS, preferably with Python 3.x. They must have a laptop to practice, ideally with a GPU.

One can also work on Google colab for free.

Syllabus

The course aims to give a theoretical and practical mastery of the basics of the field.

Regarding the theoretical aspects, it will introduce artificial neural networks and related methods (regularization, optimization), as well as the main architectures of deep learning, convolutional and recurrent networks. It will also discuss some more cutting-edge state-of-the-art topics, in particular generative networks. In addition, the course will focus on putting the methods into practice and will present applications in various fields (vision, language, speech, decision, etc.).

Finally, the course will address the ethical aspects related to the techniques discussed. It gives examples of common bias in the field and deal with recent researches that address the corresponding issues. It also proposes a general ethical framework to deal with future issues that the students may meet during their career.

Practical aspects will be discussed in class as well as during four tutorials. It is also requested to carry out a project that participates in the evaluation. The four tutorial are implemented in Python, with the PyTorch deep learning frameworks. Starting from the basics, they then review the main architectures (MLP, CNN, BiLSTM) as well as the transfer learning and fine tuning.

Class components (lecture, labs, etc.)

This "deep learning course" is made of
- three 3h lectures
- seven 1h30 lecture
- six 1h30 practice

During practice, PhD student that are expert in PyTorch are responsible for supervising smaller groups of 20 to 30 students. They also help to project, giving support to design the experiment and implement or analyze them.

Grading

The assessment is carried out by means of an assignment (1.5 hour) comprising course questions and problems. Optionally, a group project of 1 to 3 people may be carried out, which may increase the grade obtained in the assignment.

Course support, bibliography

Ian Goodfellow and Yoshua Bengio and Aaron Courville. *Deep Learning*. MIT Press, 2016 https://www.deeplearningbook.org/

Michael Nielsen. *Neural Networks and Deep Learning* , dec. 2019 http://neuralnetworksanddeeplearning.com/

Yann LeCun, Yoshua Bengio & Geoffrey Hinton. *Deep Learning*, Nature, vol 521, pp 436-421, 28 May 2015

Dive into Deep Learning https://d2l.ai/index.html

Learning outcomes covered on the course

- overview and history of the field; basics in machine learning and optimization
- main principle to design neural networks (NN) and learn them; application to multi-layer perceptron (MLP)
- convolutional and recurrent NN; application to computer vision and natural language processing (NLP)
- neural models based on attention (transformers)
- more advanced concept for regularization and NN optimization
- unsupervised models, in particular generative ones (GAN and VAE). Control of generative models, exploring their latent space.
- multi-task learning applied to vision/NLP tasks
- transfer learning, webly supervised learning
- NLP models: textual embeddings, Transformers and BERT
- frugality, semi-supervised learning
- ethic aspects of deep learning; existing bias in the field; ethic dilemna
- practice with PyTorch (or possibly Tensorflow 2.0) for several models: MLP, CNN, (bi)LSTM; application to transfer learning, GAN

Description of the skills acquired at the end of the course

The person who follow this module will know the main theoretical concept of deep learning. They will know how to implement the most known architectures and use them to solve simple problems. This is part of the C6.4 competency ("Solving problems in a computational thinking approach").

Those who already know deep learning (or are particularly motivated) will be able to go deeper in the theory and better understand come advanced concepts related to the field. This is part of competency C2.1 ("Having pursued a field or discipline related to the basic or engineering sciences").

The course addresses ethical issues related to deep learning and thus contributes to the acquisition of competencies C9.1 ("Understand and analyze the possible consequences of one's choices and actions") and C9.2 ("Perceive the scope of responsibility of the structures to which one contributes, integrating environmental, social and ethical dimensions")

Throught the project, all will produce a significant outcome with deep learning techniques, solving a problem for which they feel particularly motivated. Those who will be working in groups will mobilize competency C8.1 ("Teamwork/Collaboration") skills. In all cases, it will enforce competency C2.5 ("Mastering the skills of one of the basic engineering professions (at the junior level)") and C3.6 ("Evaluating the efficiency, feasibility and robustness of proposed solutions")

3IF3030 – Knowledge and Reasoning

Instructors : **Fabrice Popineau**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The knowledge economy is very concretely reflected today by the fact that many large companies working on information (NY Times, Bloomberg, Facebook, Microsoft, Google, etc.) have invested heavily in the creation of "knowledge graphs". It is also by this means that Google has been able to enrich the responses to user queries on its search engine and its voice assistant. These knowledge graphs represent symbolic and structured knowledge that is expressed using formal languages. Various forms of logic are used to reason about this knowledge. The explanation and justification of decisions and analyses produced by AI systems also rely heavily on the ability to manipulate such knowledge. The objective of this course is to introduce the issues and techniques to handle these types of knowledge.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Logic Modeling and Formal Systems course in SD9

Syllabus

Introduction (3EPA)
- Expressing knowledge
- Semantics - Relationship between natural language and formal language
- Logic as a universal language
- Objectives of the module
- Demonstrations

Knowledge representation (6EPA)
- Description Logics
- AL language and extensions
- Ontological reasoning
- Tableaux Method
- Complexity vs. expressiveness
- OWL
- Protégé

Semantic Web (6EPA)
- Knowledge engineering
- Knowledge graphs
- SPARQL
- Upper level ontologies
- Representation of spatial, temporal, etc. knowledge.

Reasoning (6EPA)
- Rules languages
- SWRL
- Negation and defaults
- Induction, deduction, abduction

- Answer Set Programming (ASP)

Future (3EPA)
- From logic programming to probabilistic programming
- Neuro-symbolic approaches

Class components (lecture, labs, etc.)

The 3-hour sessions are a mix of lectures and tutorials.
Concepts are introduced and immediately illustrated
by practical application.
Students can follow up the exercises with personal work.

Grading

The final grade will be based on :
Continuous assessment: 30%
Project: 70%

The project will consist of working in pairs or trios on a topic.
Topics will be provided at the beginning of the module.

Course support, bibliography

- Gelfond, M., & Kahl, Y. (2014). Knowledge Representation, Reasoning, and the Design of Intelligent Agents: The Answer-Set Programming Approach. Cambridge: Cambridge University Press. doi:10.1017/CBO9781139342124
- Ronald Brachman & Hector Levesque (2004). Knowledge Representation and Reasoning https://www.elsevier.com/books/knowledge-representation-and-reasoning/brachman/978-1-55860-932-7
- Kejriwal, M., Knoblock, C. A., & Szekely, P. (2021). Knowledge Graphs: Fundamentals, Techniques, and Applications. MIT Press. https://mitpress.mit.edu/books/knowledge-graphs
- Baader, F., Calvanese, D., McGuinness, D., Nardi, D., & Patel-Schneider, P. (Eds.). (2007). The Description Logic Handbook: Theory, Implementation and Applications. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511711787 https://www.cambridge.org/core/books/description-logic-handbook/F050683766E57EE9BB07BC01BB7A7069

Resources

- Teaching team (names of the teachers of the lectures): Fabrice Popineau - XXX
- TD size (default 35 students): 25 students
- Software tools and number of licenses required: free software that can be installed on students' machines
- Public works rooms (department and capacity) : N/A

Learning outcomes covered on the course

By the end of this unit, students will be able to :

- represent knowledge using formal languages,
- reason with formal procedures about this knowledge,
- model real problems in this framework using dedicated tools.

Description of the skills acquired at the end of the course

- Competency C1.2 - Modeling: use and develop appropriate models, choose the right modeling scale and simplifying assumptions
- Competency C1.4 - Design: specify, produce and validate all or part of a complex system
- Competency C2.1 - Go deeper into an engineering or scientific discipline
- Competency C6.3 - Process data
- Competency C8.1 - Build a collective to work as part of a team

3IF3040 – Decision systems

Instructors : **Vincent Mousseau**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **50**
On-site hours (HPE) : **30,00**

Description

Preferences are present and pervasive in many situations involving human interaction and decisions. Preferences are expressed explicitly or implicitly in
numerous applications and relevant decision should be made based on these preferences. This course aims at introducing preference models for decisions, in particular in a multicriteria setting, for decision under uncertainty, and for collective choice.
We will present concepts, methods and algorithms for preference modelling and decision making.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

Main concepts for multicriteria decisions,
decision under uncertainty, utility theory, decision-hazard trees
Voting procedures , Social choice theory,
computational social choice
Aggregation procedures grounded on a synthesis criterion
Aggregation procedures based on binary relations, outranking methods
Preference learning
Portfolio decision analysis
Behavioural aspects of decision making
Applications on the Decision Deck platform

Class components (lecture, labs, etc.)

Lecture courses and exercise classes
implementations

Grading

Project + final exam

Course support, bibliography

- Salvatore Greco, Jose Figueira, Matthias Ehrgott, "Multiple criteria decision analysis: State of the Art Surveys" Springer, 2005.
- Ralph Steuer. "Multiple Criteria Optimization: Theory, Computation and Application", John Wiley, New York, 1986.
- Denis Bouyssou, Didier Dubois, Henri Prade and Marc Pirlot "Decision-Making Process, Concepts and Methods", Wiley, 2009.
- Denis Bouyssou, Thierry Marchant, Patrice Perny, Marc Pirlot, Alexis Tsoukiàs, Philippe Vincke. "Evaluation and

Decision Models: a critical perspective", Springer-Verlag, 2001.
- Denis Bouyssou, Thierry Marchant, Marc Pirlot, Alexis Tsoukias, Philippe Vincke. "Evaluation and Decision Models with Multiple Criteria:
Stepping stones for the analyst", Springer-Verlag, 2006.

Resources

Course material (slides) + exercise sheets (TD) + some video lessons

Learning outcomes covered on the course

At the end of the course, students will have assimilated concepts, models and algorithms allowing them to implement decision support solutions in concrete applications and situations

3IF3050 – Explainable Artifical Intelligence

Instructors : **Jean-Philippe Poli**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

Artificial Intelligence aims to solve problems automatically. In particular, Deep Learning allows reaching performances that are often greater than human performances.
However, in some application areas, users want to understand why an algorithm proposes a certain decision. This is especially true for human-centered domains, such as medicine and security, or for those that are affected by laws offering a right to explanation (banking sector).

For these reasons, the field of XAI (eXplainable Artificial Intelligence) has become very important in recent years, even though the issue has been around for several decades.

This module aims to introduce you to the tools that have emerged from recent or older researches and that help to understand the most opaque models, and to familiarize you with interpretability and explainability issues.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Machine learning (mention AI)

- Statistics and probabilities
- Python programming

Syllabus

Interpretability / local / global explainability

- Interpretable models
- Post-hoc interpretability
- Evaluation
- Research in progress

Grading

Some practical works will be evaluated.

Resources

Teaching team : Wassila Ouerdane and Jean-Philippe Poli
Software tools:
python 3.x
notebook jupyter or personal IDE

Learning outcomes covered on the course

At the end of this course, the student will have acquired
- a general view of the XIA domain and its problems
- a knowledge and practice of the latest algorithms in the field
- an opening on research problems

Description of the skills acquired at the end of the course

- C1: Analyze, design and build complex systems with scientific, technological, human and economic components
- C2: Develop in-depth skills in a scientific or sectoral field and a family of professions
- C6: Being comfortable and innovative in the digital world
- C3: Act, undertake, innovate in a scientific and technological environment
- C9: Think and act as an ethical, responsible and honest engineer, taking into account environmental, social and societal dimensions

3IF3060 – Contests and study cases

Instructors : **Jean-Philippe Poli**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

The challenge aims at applying your knowledge about AI to real data and concrete applications.

This allows you to get off the well-marked paths that you are used to in practical works and to confront yourself, before your internship, with all the difficulties that you may encounter.

For this, you will be accompanied by trainers in order to carry out your mission, in a relatively short time.

Prerequisites (in terms of CS courses)

Knowledge in artificial intelligence and machine learning, data science.
Programming in Python 3.X

Syllabus

There is no pedagogical content in this EU. Its goal is to mobilize your knowledge and creativity to solve a decision problem.

Grading

Each group will present their work to a jury.

Resources

The class will be divided into groups. Each group will develop its approach.

Learning outcomes covered on the course

C2: Develop in-depth skills in an engineering field and in a family of professions
C6: Be operational, responsible and innovative in the digital world
C3: Act, undertake, innovate in a scientific and technological environment
C7: Knowing how to convince
C8: Lead a project, a team

Description of the skills acquired at the end of the course

Data Ops
ML Ops

3IF3210 – Reinforcement Learning

Instructors : **Hédi Hadiji**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS, ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Reinforcement learning is a powerful paradigm of artificial learning that allows autonomous systems or agents to learn how to make good decisions. It is applicable to a wide range of tasks such as robotics, games or autonomous systems. The objective of this course is to present the fundamentals of reinforcement learning as well as its main approaches and challenges.

Quarter number

SG11

Prerequisites (in terms of CS courses)

- Basics on machine learning.
- Deep learning.
- Basic knowledge on Linear Algebra.
- Statistics and probabilities.
- Programming.

Syllabus

The following subjects will be presented :

- Overview
- Optimal Control
- Model-based MDP
- Planning
- Deep reinforcement learning

Class components (lecture, labs, etc.)

Balance between theory and practice.

Grading

The evaluation will consist of a project with a detailed report.

Course support, bibliography

- Reinforcement Learning: An Introduction, Sutton and Barto, 2nd Edition (http://incompleteideas.net/book/the-book-2nd.html)
- Algorithms for Reinforcement Learning. Cs. Szepesvari, 2009 (http://chercheurs.lille.inria.fr/~munos/master-mva/docs/Csaba_book.pdf)

Resources

- Teaching staff : Hédi Hadiji and some teaching assistants
- Size of the groups of TD /TP: 25

Learning outcomes covered on the course

At the end of this course, the student will have acquired:

- A thorough knowledge of the fundamental principles of reinforcement learning.
- Knowledge of the main algorithms of reinforcement learning and their implementation.
- Knowledge of the main environments available for reinforcement learning.
- For a given problem, a knowledge of how to formalize it as a RL problem or not.
- A knowledge of RL algorithm analysis criteria and techniques for evaluating algorithms according to these parameters.

Description of the skills acquired at the end of the course

The theoretical content of the courses, which describe the mathematical principles underlying RL algorithms, will be systematically joined to practical work sessions where these principles will be illustrated. The main skills used during this course will be:

C1.1 `Analyze the global behavior of a complex system' Students will examine in detail the global behavior of reinforcement learning agents in complex environments. They will analyze the evolution of agent behavior and the influence of various parameters during training.

C1.3 - Estimating parameter values and evaluating approximation quality' Students will be required to estimate the impact of various parameters of reinforcement learning models from data. Their modeling choices will be guided by their ability to assess the quality of the approximations made based on the agent's performance in simulated environments.

C1.4 - 'Prototype, realize and validate complex systems': Students will design, implement and validate reinforcement learning agents on simulation environments, exploring different configurations and evaluating performance according to specific criteria.

The weekly practical sessions, as well as the final project will allow students to "**Integrate, consolidate the new skills acquired within a body of knowledge (C2.2)**", as well as to "**Lead a global project in a field of science (C2.1)".**

Students will be exposed to real use cases where reinforcement learning (e.g. in train switching, arranging electronic components on a processor, or controlling a nuclear reactor) is applied in professional contexts, thus preparing them to meet the challenges of the real world. ``**C2.5 - Leading a project in a professional context**"

The course is based on numerous numerical examples and practical applications at each session, during which students will implement the methods seen in class on classic RL environments (gymnasium). All of these examples will get students to use advanced programming concepts. Students will thus be able to '**C6.1 - Solve a problem numerically' and 'C6.2 - Design software**'. They will also be interested in how training data is generated, and its impact on the trained agent. '**C6.3 - Process data**'

The final evaluation is made on a complete RL project requiring the entire design of an algorithm to solve a complex task (for example: an AI for a board game), as well as the writing of a report describing the theoretical justifications of the approach, as well as the organization of the team. Thus all the skills of the C8 block will be mobilized and evaluated, in particular: ``**C8.1 Work independently and interdependently towards a common objective**", ``**C8.3 - Contribute to the development of the skills of team members**" and `` **C8.4 - Have a critical look at the functioning of a project**".

3IF3220 – Responsible AI

Instructors : **Céline Hudelot**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

The objective of this module is to sensitize students to the notion of responsible AI, following the example of recent initiatives such as UNESCO: https://en.unesco.org/artificial-intelligence.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Conferences on various topics dealing with social and responsible IA - Activiies with existing projects.

Class components (lecture, labs, etc.)

Conferences - Debates - Idea Workshops

Grading

Noted case study

Course support, bibliography

- EC White Paper: Artificial Intelligence A European approach based on excellence and trust
- Valérie Beaudouin, Isabelle Bloch, David Bounie, Stéphan Clémençon, Florence d'Alché-Buc, et al. Flexible and Context-Specific AI Explainability: A Multidisciplinary Approach. 2020

Resources

Conferences - Study cases - Working groups.

Learning outcomes covered on the course

Knowing how to consider an AI system as a whole, taking into account its societal and environmental impact.

Description of the skills acquired at the end of the course

This course will mobilize the following skills:

+ C 2.5: "Develop the know-how and interpersonal skills of one of the engineering professions".
+ C6: "Be operational, responsible and innovative in the digital world".
C3: "Act, undertake and innovate in a scientific and technological environment" + C9: "Act, undertake and innovate in a scientific and technological environment
+ C9: "Act, undertake, innovate in a scientific and technological environment".

3IF3240 – Visual recognition and Multimedia Processing

Instructors : **Céline Hudelot**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Computer vision is more and more omnipresent in our society with many applications in our daily life or in the industrial sector (robotics, multimedia search engines, mobile applications, image-based medical diagnosis, autonomous cars...). The objective of this course is to present the fundamental principles and recent advances, as well as the important applications of computer vision. The course will focus, in particular, on the visual recognition tasks that are often at the heart of these applications. The course will also present the case of multimedia data (videos, text-image...).

Quarter number

SG11

Prerequisites (in terms of CS courses)

- Machine Learning
- Deep Learning
- Basic knowledge on Linear Algebra
- Python programming
- Signal processing

Syllabus

The following topics will be covered both in class and in the practical sessions:

- Human Vision / Artificial Vision.
- Image Formation - Image Geometry.
- Introduction to Image Processing: filtering ...
- Feature Detection and Matching.
- Segmentation.
- Recognition.
- Motion.
- Calibration - 3D reconstruction.
- Multimedia data.

Class components (lecture, labs, etc.)

Each 3 hour-session will consist of 1h30 of class and 1h30 of direct practice of the concepts seen in the course. This practical application will be done in the form of practical work with python notebooks.

Grading

The evaluation will consist of a 40% continuous assessment, which will consist of handling in and scoring some of the practical work. The rest of the assessment (60%) will consist of a free project in teams of 2 to 3 students.

Course support, bibliography

- Szeliski, Computer Vision: Algorithms and Applications, Springer, 2010 (on line : http://szeliski.org/Book/)
- Hartley and Zisserman, Multiple View Geometry in Computer Vision, Cambridge University Press, 2004 (https://www.robots.ox.ac.uk/~vgg/hzbook/)
- Forsyth and Ponce, Computer Vision: A Modern Approach, Prentice Hall, 2002 (https://www.pearson.com/us/higher-education/program/Forsyth-Computer-Vision-A-Modern-Approach-2nd-Edition/PGM111082.html)

Resources

- Teaching staff: Céline Hudelot and an assistant lecturer
- Size of the TD /TP: 25 (2 groups)
- Software tools and technical environment :
    - Programming language: python and the opencv library (https://opencv.org/opencv-4-4-0/).
    - Development environment: jupyter notebook or IDE of the student's choice.

Learning outcomes covered on the course

At the end of this course the student will have acquired:

- A thorough knowledge of the fundamental principles of image processing and computer vision.
- A knowledge of the main algorithms used for the main applications of computer vision and in particular high-level tasks such as visual recognition.
- Knowledge of the choice and implementation of methods adapted to the design of a vision system in a specific context.
- Know-how concerning the evaluation of the performance of a vision system.

Description of the skills acquired at the end of the course

A thorough knowledge of the fundamental principles of image processing and computer vision and a knowledge of the main algorithms used for the main applications of computer vision, in particular high-level tasks such as visual recognition, are required for **C2.1 "A thorough knowledge of a field or discipline related to basic sciences or engineering sciences".**

Know-how concerning the choice and implementation of methods adapted to the design of a vision system in a specific context is part of **C1.4 "To specify, design, realize and validate all or part of a complex system", C3.5 "To propose new solutions/tools either in rupture or in continuous progress".**

Know-how concerning the evaluation of the performance of a vision system is part of **C3.6 "Evaluate the efficiency, feasibility and robustness of the proposed solutions" and C3.7 "Select solutions and act in a pragmatic way, in order to obtain tangible results".**

Competencies **C6.4 "Solve problems in a computational thinking approach" and C6.5 "Exploit all types of data, structured or not, including massive data"** will also be mobilized.

3IF3250 – Automated planning

Instructors : **Anaëlle Wilczynski**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Planning in AI focuses on automatically generating sequences of actions that must be performed in order to reach a predefined goal. Actions are represented by operators transforming the states, generally expressed via propositional logic. Several problems in industry or robotics can be formulated as planning problems. Different AI techniques and algorithms are used to solve planning problems. In classical planning, an agent has perfect knowledge of the states and the effects of the actions, which are deterministic. The relaxation of these assumptions leads to numerous extensions using solving techniques based on diverse AI tools like heuristic search or Markov processes.
In this course, we will introduce the formulation of a planning problem and present the different AI techniques and algorithms for solving it, with planners from the state of the art and classical examples of planning problems. The practical dimension is emphasized with a project to realize during practical tutorials.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Basic knowledge in propositional logic and programming

Syllabus

Planning problem and PDDL language; classical planning, heuristics and planners; conformant and contingent planning; probabilistic planning.

Class components (lecture, labs, etc.)

Lectures and (practical) tutorials

Grading

Project and assessment test

Course support, bibliography

- Hector Geffner and Blai Bonet. A concise introduction to models and methods for automated planning. *Synthesis Lectures on Artificial Intelligence and Machine Learning*, 8(1):1–141, 2013
- Malik Ghallab, Dana Nau, and Paolo Traverso. *Automated Planning: theory and practice*. Elsevier, 2004
- Steven M. LaValle. *Planning algorithms*. Cambridge University Press, 2006
- Stuart J. Russell and Peter Norvig. *Artificial Intelligence: A Modern Approach*. Pearson, 2003
- Régis Sabbadin, Florent Teichteil-Königsbuch, and Vincent Vidal. Planning in Artificial Intelligence. In *A Guided Tour of Artificial Intelligence Research*, pages 285–312. Springer, 2020

Resources

Slides

Learning outcomes covered on the course

AI techniques and algorithms for planning, global view of the different planning problems and approaches.

Description of the skills acquired at the end of the course

Modelling and formalizing a planning problem, knowing the different AI approaches used in planning, choosing solving techniques adapted to a particular planning problem.

Identified skills:
- C1: Analyze, design and implement complex systems with scientific, technological, human and economic components
- C2: Acquire and develop in-depth expertise in a scientific or sectorial field and/or job
- C6: Thrive and innovate in the digital world

3IF3260 – Human Sciences and Artificial Intelligence

Instructors : **Nicolas Sabouret**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

This course aims at showing how social and human sciences can contribute to the conception of intelligent interactive systems and, conversely, how AI can contribute to the study of human beings. Based on a case study (conception of an expressive conversational agent), we present a theoretical and methodological approach to design the AI model based on psychological theories of human cognition and emotions. We show how to design and conduct experiments to study the effect of such an AI model on the perception of the agent by human users.
Additional note: all sessions will be in French

Quarter number

SG11

Prerequisites (in terms of CS courses)

- Advanced imperative programming (C/C++/Java)
- Basics in Knowledge Representation
- Basics in Statistical Machine Learning

Syllabus

- **Session 1: Introduction to HCI.** What is Human-Computer Interaction? What is an embodied conversational agent? How does this work?
- **Session 2: Introduction aux Human Science.** What is an experimental protocol in HS? How can we validate an AI system that interacts with human users? How can we take into consideration the ethical questions in the model design and in the protocol? What is an ``ecological'' situation?
- **Session 3: HS models for AI.** What models of emotions, as defined by research in social psychology and cognitive psychology, can be used in AI? How can we implement them?
- **Session 4: Affective dimensions and non-verbal expressions.** How to express the affective states in the behaviour of a conversational agent? What are the physiological and computational models?
- **Session 5: Perception of behaviours.** What are the the high-level processes (judgements) and low-level processes (perception) of the agent's behaviour? How can these be measured?
- **Session 6: Statistical analysis.** What statistical analysis can be used on the experimental results? How can these results be interpreted Comment interpréter ces résultats with respect to the aims of the AI model?

Class components (lecture, labs, etc.)

The sessions are lecture+practical sessions of 3h each, in which the students can immediately apply the theoretical concepts. The sessions will be supervised by AI and HS researchers:
• Brian Ravenet, Nicolas Sabouret (AI)
• Céline Clavel, Elise Prigent (HS).
The progression is organized around a project (implementation of a conversational agent and evaluation) a along the sessions.

Grading

The evaluation will be based on the work done all along the tutorial sessions for the project that supports the course's theoretical models. The work will be done in groups of 2 students. Each group must prepare a report and an oral presentation that answers the following questions. Which methodology was involved in the design of the system? What the technical choices did you do for the design of the agent, in terms of affective model and emotion expression? Which scientific question about human-AI interaction is studied in this protocol?

Course support, bibliography

- Picard, R. W. (2000). *Affective computing*. MIT press.
- Minsky, M. (2007). *The emotion machine: Commonsense thinking, artificial intelligence, and the future of the human mind*. Simon and Schuster.
- Russel A. Jones. (2000). *Méthodes de recherche en sciences humaines*. De Boeck Supérieur. (in French)

Resources

Each session of 3 hours will be composed of a lecture grouped with practical work, in which the students can immediately apply the theoretical concepts. The case-study is the development of a conversation agent using an existing platform in C++ or Java. No specific material is required. All softwares (Unity, C#, bibliothèques Python, OpenSesame, JASP) can be downladed freely.

Learning outcomes covered on the course

After this course, students will be capable of:

- Design a computational model that reproduces human behaviours cognitive phenomenons
- Design and implement an evaluation protocol for an AI system that interacts with a human being, so as to study the impact of the AI model on the perception of the user
- Gather theoretical and methodological work in psychology to design an AI model

Description of the skills acquired at the end of the course

This course contributes to the development of competences C1.1, C1.4, C2.2, C5.2, C6.3, C8.1, C8.3, C8.4 and C9.5

3IF3270 – Large scale graph mining

Instructors : **Nacera Seghouani**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Data we produce or consume has increasingly networked structures which have grown in complexity in different domains such as biology, social networks, economy, communication and transport networks. The need to process and to analyze such data carries out the emergence of network science research community to define algorithms which allow to characterize such complex structures, to understand their topology, their evolution and to interpret the underlying phenomena.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Graphs and algorithms basic concepts

Syllabus

Preliminaries: Some linear algebra basics, Centrality and similarity metrics
Random walk, Hits & PageRank
Typology of graphs: Power-Law, Random, Uniform, and other properties of real networks such as giant components and six degrees separation
Studying community detection, label propagation, influence maximisation and graph partitioning, tracking link formation and prediction, graph sampling
Graph embeddings and graph neural networks (GNN). Different kind of graphs (social networks, knowledge graphs).

Class components (lecture, labs, etc.)

5 x 3h lectures
2 x 3h lab assignments/mini-project

Grading

Mini-Project + Scientific papers reading

Resources

Slides, practical exercices/works, MQCs
Bibliography references

Learning outcomes covered on the course

Foundations and algorithms for graph analytics
Foundations for graph neural networks (GNN)

Description of the skills acquired at the end of the course

- Analyse, design and implement complex systems made up of scientific, technological, social and economic dimensions: **C1.1** Examine problems in their entirety and beyond their immediate parameters.
- Identify, formulate and analyse the scientific, economic and human dimensions of a problemAcquire and develop broad skills in a scientific or academic field and applied professional areas: **C2.1** Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.
- Act, engage, innovate within a scientific and technological environment: **C3.6** Evaluate the efficiency, feasibility and strength of the solutions offered. / proposed solutions
- Advance and innovate in the digital world: **C6.4** Solve problems through mastery of computational thinking skills.

3IF3280 – Multi-agents systems

Instructors : **Wassila Ouerdane**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Multi-agent systems (MAS) are currently widely used, especially for complex applications requiring interaction between several entities. More specifically, they are used in applications where it is necessary to solve problems in a distributed manner (data processing) or in the design of distributed systems in which each component has some degree of autonomy (control of processes). Some examples of applications are trading agents, drones, smart grids. This course will begin with an introduction to the notion of agent and multi-agent systems. It will present the concepts that will lead to an understanding of what an agent is and how it can be built. Then, we will address a classical problem of SMAs, namely how to model and simulate a situation through the concept of agents. The idea is to give a basis for understanding how agent-based simulations can be used as a tool for understanding human societies or complex problems and situations. Besides, we will discuss how agents can communicate and interact to solve problems, and more specifically, to make non-centralized decisions. For this, we will rely on negotiation protocols based on argumentation theory, a process of constructing and evaluating arguments (positive and negative reasons/evidence) to resolve conflicts.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Information System and Programming (SIP, SG1), Algorithmics and Complexity (ST2), all the courses of the SD9 Computer Science.

Syllabus

1- Content of the course sessions:

- Introduction to multi-agent systems: basic notions around the concepts of agent and multi-agent system, some architectures and application domains.
- Multi-agent simulation: introduction to the concept of simulation and its implementation in multi-agent systems.
- Multi-agent problem solving: we will discuss notions and concepts that will allow us to support and implement a distributed decision between autonomous entities. In particular, we will discuss:
  - Interaction mechanisms (direct and indirect interactions, interaction protocols, ...)
  - Coordination mechanisms (some coordination tools: focus on the argumentation system and dialogue systems based on negotiation)

2- Contents of the Practical Work sessions:

Practical work is planned for the practical application of the concepts and notions seen in each part of the course. These TPs will be done in Python. Two subjects will be realized:

- The first one will be dedicated to multi-agent simulation.
- The second one will be dedicated to the implementation of a distributed decision problem.

Class components (lecture, labs, etc.)

- Each session will be composed of a lecture and a practical part.
- The default language of the course is French, but English can be used as the language of instruction.

Grading

The evaluation of the course in based on the practical works carried out during the course. A report ais expected at the end of the course.

Course support, bibliography

- Ferber, J. (1995), *Les Systèmes Multi-Agents*, InterEditions. (French version)
- Ferber, J. (1999), *Multi-agent systems: An introduction to distributed artificial intelligence*, Addison Wesley. (English version)
- Michael Wooldridge (2002), *An Introduction to MultiAgent Systems*, John Wiley & Sons Ltd.
- The AgentLink roadmap
- Robert E. Shannon (1977), *Simulation modeling and methodology*, SIGSIM Simulation Digital.
- Robert E. Shannon (1998), *Introduction to the art and science of simulation*, IEEE Computer Society Press.
- Bernard P. Zeigler (2000), *Theory of Modeling and Simulation*, Academic Press, Inc.
- Rahwan, Iyad (2009), *Argumentation in Artificial Intelligence*,Springer.
- Lopes, Fernando & Coelho, Helder. (2014). *Negotiation and Argumentation in Multi-Agent Systems: Fundamentals, Theories, Systems and Applications*. Bentham Science Publishers.
- Argumentation in Multi-Agent Systems (ArgMAS) Workshop Series

Resources

- Teaching team: Wassila Ouerdane, Nicolas Sabouret
- Languages, Softwares:
    - Python.
    - Mesa (https://mesa.readthedocs.io).

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:

- Understand the concepts of artificial agent and multi-agent systems.
- Distinguish several multi-agent system architectures.
- Understand the different applications of multi-agent systems.
- Implement a simple mechanism for negotiation between agents to resolve a decision problem.

Description of the skills acquired at the end of the course

At the end of this course, students will be able to:

- C1: Analyse, design and implement complex systems made up of scientific, technological, social and economic dimensions.
- C2: Acquire and develop broad skills in a scientific or academic field and applied professional areas
- C3.6 Evaluate the efficiency, feasibility and strength of the solutions offered/proposed solutions

3IF3300 – Advanced natural language processing with deep learning

Instructors : **Pierre COLOMBO**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

This course is intended for students who are interested in the latest advances in research in artificial intelligence and related fields with an interest in their application in a research or innovation process.
Students will read, present and discuss scientific papers on a given leading-edge topic and will complete a mini-project or case study on the topic.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Fundamentals courses in Artificial Intelligence

Syllabus

Topics will include, for example, self-directed learning or meta-learning, "hybrid" AI, explanatory argumentation, causal and counterfactual reasoning, knowledge revision etc.
It will depend on the different topics proposed by the teaching team.

Class components (lecture, labs, etc.)

- The course will rely heavily on the reading of recent articles on the chosen topic selected by the teaching team.
- Reading groups will be set up for the restitution and discussion of these articles.
- For certain subjects, master classes may also be set up.
- The course will include an application through a case study or a mini-project...

Grading

The course will be evaluated through the realization of a mini-project on the topic chosen by the group.

Course support, bibliography

According to the topic

Resources

- Teaching team: teachers/researchers in AI from CentraleSupélec or Paris Saclay University.
- The work will be done in groups of 2 to 3 students.

Learning outcomes covered on the course

At the end of this teaching, the student will know:

- study and discuss a cutting-edge subject in a rigorous scientific or innovative approach.

They will also have acquired the following knowledge:

- a knowledge of several recent and current fields of artificial intelligence.

Description of the skills acquired at the end of the course

This course will mobilize the following skills:

- C2.1: Have a thorough knowledge of a field or discipline related to the basic or engineering sciences.
- C2.4 To create knowledge, in a scientific process.
- C3.5 Propose new solutions/tools that are either out of date or in continuous progress.
- C8.1 Work in team/collaboration.
- C9.4: Demonstrate rigour and critical thinking in approaching problems from all angles, scientific, human and economic.

3IF3310 – Game theory

Instructors : **Christophe Labreuche, Céline Hudelot**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

The aim of this course is twofold. First, we present the main principles concerning decision under uncertainty, and we focus on the use of graphical models when making decision under uncertainty. In this framework, we show how probabilistic computations can be performed efficiently, and that learning such graphical model (structure and/or parameters) can be based on data. We study in particular dynamic Bayesian networks, which allow probabilistic reasoning while incorporating time. Second, we consider principles of game theory and show how such theory can model and analyse decision in situation where uncertain and strategic interactions are involved.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

- Introduction : Introduction: Concepts and key notions for decision theory under uncertainty (preferences, decision criteria, risk aversion, Von Neumann Morgenstern expected utility)
- Probabilistic uncertainty representation: in real-world decision problems, representing uncertainties using probabilities often implies to use probability distributions of large size which require specific storage and computing techniques. We will present how Bayesian networks can efficiently perform these two tasks. How can Bayesian networks be transformed in order to model, in a straightforward way, a system with which a user can interact? We consider the case of influence diagrams, which allow encoding decision trees in a compact way, and we will consider the algorithmic aspects for computing on such networks.
- Non-cooperative games: We are interested here in cases where players have divergent objectives and try to maximize their own benefit only.
- Cooperative games: We are interested here in cases where players have, due to the decision situation, specific interest to cooperate.
- Application to negotiation

Class components (lecture, labs, etc.)

Lectures notes and practicing exercices

Grading

- Writen exam during last course (all documents are allowed)

Course support, bibliography

- G. Chalkiadakis, E. Elkind, M. Wooldridge. Computational aspects of cooperative game theory, 2012.
- von Neumann, John and Oskar Morgenstern,Theory of Games and Economic Behaviour, Princeton University Press, 1947.
- Gilboa, Itzhak, Theory of decision under Uncertainty, Cambridge University Press, 2009.
- Savage, Leonard J., The Foundations of Statistics, Dover, 1954
- Myerson, Roger B., Game Theory: Analysis of Conflict, Harvard University Press, Cambridge (MA), 1991.

3IF3320 – Hybridization of artificial intelligence techniques

Instructors : **Wassila Ouerdane, Céline Hudelot**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Hybrid AI refers to the set of artificial intelligence approaches that combine explicit knowledge representation approaches (whatever their form) with data-driven learning approaches. It is a field that is being studied more and more, particularly as the combination of learning and knowledge engineering can help to meet the future societal, environmental, commercial and fundamental challenges of AI.
The aim of this course is to present the main approaches, recent advances and applications, particularly in engineering, in this field.

Prerequisites (in terms of CS courses)

- Machine Learning (mention AI).
- Deep learning (mention AI).
- Representation of knowledge and reasoning (mention AI).
- Mathematical modelling (1A and 2A CS)
- Basic knowledge of linear algebra.
- Python programming

Syllabus

The following subjects will be covered both in class and in practical sessions enabling them to be put into practice.

- Introduction, motivations and taxonomy of the different approaches.
- Knowledge in the form of algebraic and differential equations:
- Learning and scientific calculation
- Learning differential equations
- Physically informed learning
- Operator learning
- Knowledge in the form of logical expressions, graphs or ontologies
- Logic neural networks
- Knowledge distillation
- Differentiable inductive programming
- AI-human hybridisation

Class components (lecture, labs, etc.)

Each 3-hour session will consist of 1.5 hours of class and 1.5 hours of direct practical application of the concepts covered in the course. course. This practical application will take the form of Python notebooks.

Grading

Assessment will consist of continuous assessment (submission of some practical work) and an MCQ at the end of the course.

3IF3500 – Infonum AI Project

Instructors : **Céline Hudelot**
Department : **MENTION INTELLIGENCE ARTIFICIELLE (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

The third year project allows students to apply their skills in an industrial or research project with the corresponding business constraints. In particular, it allows them to discover the different facets of the professions they will be able to carry out. These are the projects of the "Computer and Digital Sciences" major, including "Computer Systems Architecture", "Cybersecurity", "Artificial Intelligence" and "Software Science".

The objectives of the project are

- The development of a "product" meeting the needs of a client (company, laboratory, association, students).
- The implementation of a rigorous methodology to go from the idea to the "product".
- The continuation of learning project management.
- Demonstrating the ability to present in writing and orally in a professional context.

Quarter number

SD9 SG10 SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Depending on the project. The projects can be either Dominant projects and therefore cover themes developed in at least two of the Dominant's mentions, or they can be mention projects and therefore address themes specific to one of the Dominant's mentions.

Class components (lecture, labs, etc.)

Work in project mode.

Grading

The evaluation will be done through a mid-project review, and mainly through the final report, the final defense, and the opinion of the project leader and client. A jury, mobilized for the final presentations, will integrate these elements to evaluate the project as a whole.

Resources

- The projects take place in teams of 2 to 3 students.
- 200 hours are devoted to the projects.
- Supervision according the project type :

    - For CEI projects (industrial study contracts), the supervision is shared between the industrialist and a teacher from the school who leads the students in their work.
    - For "Laboratories" projects proposed by a teacher, supervision is entirely provided by the teacher.
    - For all other types of projects (associations, partners, CPI), the supervision is mainly done by the person proposing the project (client), a teacher from the school ensuring the good progress of the project and the intermediate milestones.
- A mid-project point will be organized in December to ensure that the project is running smoothly.
- At the end of the project, a jury presentation will take place.

Learning outcomes covered on the course

By the end of the project, students will have learned :

- to work in teams outside the academic context
- to take into account the business constraints in the realization of a project
- manage uncertainty in the definition of expected results
- to present their project and results in a professional context

Description of the skills acquired at the end of the course

Working in teams outside the academic context is part of **C8: "Leading a project, a team**" and **C5.2 "Listening, being understood and working with people from different cultures, backgrounds and skill**s".

Presenting one's project and results in a professional context is part of skill **C7: "Knowing how to convince".**

Taking business constraints into account in carrying out a project is part of **C1: "Analysing, designing and building complex systems with scientific, technological, human and economic components", C2.3: "Identifying and rapidly acquiring the new knowledge and skills needed in the relevant fields, whether technical, economic or other", and C4: "Having a sense of value creation for one's company and one's customer".**

Managing uncertainty in the definition of expected results is part of **C3.4: "Making decisions in a partially known environment, managing the unexpected, knowing how to take risks" and C3.7: "Choosing solutions and acting pragmatically, with a view to obtaining tangible results".**

Competencies **C9: "Act as a responsible professional. Think, act ethically**" and **C6: "Be comfortable and innovative in the digital world"** can also be mobilized.

3IF4010 – Computer architecture

Instructors : **Laurent Cabaret, Stephane Vialle**
Department : **MENTION ARCHITECTURE DES SYSTÈMES INFORMATIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Knowledge of modern hardware architectures is an essential prerequisite for the construction of hardware and software IT solutions that respect energy constraints and the application needs of users in the Big Data context. This course will provide the knowledge and tools to design programs for modern architectures such as multi-core CPUs with vector extensions and GPUs.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Information Systems and Programming
Algorithmics and Complexity

Syllabus

Processor architecture
Multi-core/Multi-processor architectures
Accelerator architectures

Class components (lecture, labs, etc.)

Alternating courses and practical work allow the assimilation and rapid implementation of parallel computing concepts according to the three paradigms discussed in the course.

Grading

- Direct individual assessment during the practical sessions
- Lab reports are constrained in size to assess both the understanding of concepts and synthesis skills.

In case of unjustified absence from a practical session, a grade of 0 will be applied, in case of justified absence, the average of the other practical sessions will be applied.

Resources

CentraleSupelec Metz Computation Center

- Mésocentre

Teaching staff:

- Laurent Cabaret
- Stéphane Vialle

Learning outcomes covered on the course

At the end of this course, the students will know:
- The general principles of parallelism and parallel computing
- Processor architecture
- Vectorization of a computation code on a CPU

At the end of this course, students will know how to:
- Multithread a code on a CPU
- Massively parallelize an algorithm on a GPU architecture.
- Measure the performance of a computation code.

Description of the skills acquired at the end of the course

C1.3 Solve: solve a problem with a practice of approximation, simulation, and experimentation
C6.2 Design Software
C7.1 Basically: Structure ideas and arguments, be synthetic (assumptions, objectives, expected results, approach, and value created)

3IF4020 – Modern infrastructure & Cloud

Instructors : **Thierry Rapatout, Luc Vo Van, Francesca Bugiotti**
Department : **MENTION ARCHITECTURE DES SYSTÈMES INFORMATIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **50**
On-site hours (HPE) : **30,00**

Description

This course will provide the knowledge required to design, implement and deploy IT solutions encompassing both infrastructure (networking, storage, servers) and software (business logic, databases) aspects targeting both traditional and cloud environments.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Information Systems and Programming
Algorithmics and Complexity

Syllabus

Network, Servers and Data centers
• Fundamentals: storage, compute and networking
• Introduction to notions of cost and environmental impact
Databases
• Database concepts
• NoSQL Databases
• Graph databases
Lab: building a cloud native app leveraging heterogeneous databases
Virtualization / Cloud / Orchestration
• From fully physical environments to virtualization
• Virtualization technical principles
• Virtualization in the cloud and deployment principles
• Introduction to containers
Lab: Deployment of an application to multiple deploy targets in the cloud
Deep Dive Cloud Computing :
• Cloud service models (IaaS, SaaS, PaaS, …)
• Showcase (major cloud SaaS actor)
• Native cloud development using servless
Lab: Serverless application with Azure Logic Apps
Plateformes de Données :
• DevOps, introduction to MLOps
• Challenged faced by modern data platforms
• Principles and architecture of a data platform
• Security, sovereignty, ethics and privacy considerations
Architecture des Applications ‘Cloud native’
• Introduction to ‘cloud native’ principles
• Cloud native design patterns
• Architectural approaches: Microservices, API Management, CAP theorem, application layers, hybrid and edge
Lab: Using a cloud-based, container-packaged AI service on the edge
Kubernetes, DevOps et Infrastructure as Code
• Introduction to Kubernetes
• Introduction to l’infrastructure-as-code and ‘gitops’ using GitHub and Terraform
Lab: Infrastructure-as-Code with Terraform

Class components (lecture, labs, etc.)

Alternating courses and lab works allowing the rapid assimilation and implementation of the concepts.

Grading

Short open-ended questions

Resources

Teaching staff:

- Francesca Bugiotti
- Thierry Rapatout
- Luc Vo Van

Learning outcomes covered on the course

At the end of this course students will have a precise knowledge of:

· Fundamental components used in the design of modern, cloud ready enterprise IT architecture
· Applicable concepts, methods and tools
· Different approaches to databases, NoSQL, graphs, and their main uses.

They will have the capacity to:
· Implement fundamental services commonly available in the Cloud
· Design traditional or Cloud-oriented solution architectures
· Design SQL, NoSQL, and graph databases solutions.

Description of the skills acquired at the end of the course

C1 Analyze, design, and build complex systems with scientific, technological, human, and economic components.
C2 Analyze: study a system as a whole, the situation as a whole. Identify, formulate and analyze a system within a transdisciplinary approach with its scientific, economic, human dimensions, etc.
C7 Know how to convince

3IF4030 – Software architecture

Instructors : **Dominique Marcadet**
Department : **MENTION ARCHITECTURE DES SYSTÈMES INFORMATIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **36,00**

Description

The design of computer applications is constantly evolving with the regular appearance of new approaches which coexist with new frameworks modernizing the implementation of more mature approaches. This course will present an overview of the different application architectures and deepen the most relevant of the moment.

Quarter number

SG10

Prerequisites (in terms of CS courses)

3IF1020 : Programming labs and tools

Syllabus

- Typology of architectures
- Application integration
- Java Technologies (JakartaEE, Spring) - Service-based approach
- JavaScript Technologies (NodeJS) - Micro-services
- .Net Technologies - Cloud architectures, serverless, API Management
- Message-based architectures (Kafka)

Class components (lecture, labs, etc.)

This course consists of lectures to present the concepts and practical work allowing an operational appropriation of these concepts

Grading

Results of practical work : 100%

Course support, bibliography

Supports
- Lectures slides
- Exercises to be carried out during practical work and personal work

Resources

Teaching team:
- Dominique Marcadet
- Idir Ait Sadoune
- Benoît Valiron
- Luc Vo Van

Learning outcomes covered on the course

At the end of this module, students will:

- know the different existing application architectures
- understand the advantages and disadvantages of these architectures
- be able to design an architecture that meets specifications
- know the main technologies available to implement an application architecture

Description of the skills acquired at the end of the course

C2.1: Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences

- Knowledge of software architectures

C6.3: Design software

- Improvement of skills

3IF4040 – Economics and IT Management

Instructors : **Thierry Rapatout, Joachim Treyer, Pierre-Frédéric Rouberties, Laurent Cabaret**
Department : **MENTION ARCHITECTURE DES SYSTÈMES INFORMATIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **36,00**

Description

This course immerses students in the world of IT:

- Companies' information systems' economic stakes are treated from technical and financial angles: definition, typology, construction, and operation processes.
- The transposition of economic management to a management of the IT carbon footprint
- The technological architecture of companies at the time of the digital transformation: IT strategy, uses, and Big Data architectures in companies, process modeling, enterprise architecture planning, digital ecosystems.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Information Systems and Programming

Syllabus

- What is an Information System?
- Every company is a software company", the Cloud business model (OPEX vs. CAPEX)
- Optimization of the technical and economic performance of information systems
- Cost and Value - Economic Steering
- Agile Enterprise Architecture - Trajectory of an information system - Modern Urbanization of the Information Systems
- Digital Transformation

Class components (lecture, labs, etc.)

Theoretical contributions and case studies

Grading

Short open-ended questions

Resources

Teaching staff:

- Ygal Levy
- Thierry Rapatout
- Pierre-Frédéric Rouberties
- Joachim Treyer

Learning outcomes covered on the course

At the end of this course, the students will know:
- The economic model of the Cloud
- The business model of an IT department
- The principles of enterprise architectures
- The elements allowing the economic and ecological management of IT

At the end of this course, students will know:
- Make choices in enterprise architecture
- Analyze the structure of an IT budget
- Identifying economic performance levers
- Making infrastructure choices from a technical and economic perspective

Description of the skills acquired at the end of the course

C2 Develop in-depth skills in an engineering field and a family of professions
C4 Have a sense of value creation for his company and his customers

3IF4210 – Technical case study

Instructors : **Laurent Cabaret**
Department : **MENTION ARCHITECTURE DES SYSTÈMES INFORMATIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **15**
On-site hours (HPE) : **9,00**

Description

In addition to the scientific, technical, and methodological contributions of the different modules, the case studies will put the students face to face with concrete situations arising from business issues. This will allow the development of know-how while linking and putting into action different knowledge.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

In addition to the scientific, technical, and methodological contributions of the different modules, the case studies will put the students face to face with concrete situations arising from business issues. This will allow the development of know-how while linking and putting into action different knowledge.

Class components (lecture, labs, etc.)

Case study

Grading

Evaluation by defense and participation level

Resources

Teaching staff:
A team from the partner company

Learning outcomes covered on the course

At the end of this course, students will be able to mobilize their knowledge and skills to respond to a concrete case.
They will know how to formalize their proposal synthetically.

Description of the skills acquired at the end of the course

C2.1 Deepen a field of engineering sciences or a scientific discipline
C4.2 : Propose one or more solutions answering the question rephrased in terms of value creation and complemented by the impact on other stakeholders and by taking into account other dimensions. Quantify the value created by these solutions. Arbitrate between possible solutions
C6.2 : Design software

3IF4220 – Business case study

Instructors : **Laurent Cabaret**
Department : **MENTION ARCHITECTURE DES SYSTÈMES INFORMATIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

In addition to the scientific, technical, and methodological contributions of the different modules, the case studies will put the students face to face with concrete situations arising from business issues. This will allow the development of know-how while linking and putting into action different knowledge.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

In addition to the scientific, technical, and methodological contributions of the different modules, the case studies will put the students face to face with concrete situations arising from business issues. This will allow the development of know-how while linking and putting into action different knowledge.

Class components (lecture, labs, etc.)

Case study

Grading

Evaluation by defense and participation level

Resources

Teaching staff:
A team from the partner company

Learning outcomes covered on the course

At the end of this course, students will be able to mobilize their knowledge and skills to respond to a concrete case.
They will know how to formalize their proposal synthetically.

Description of the skills acquired at the end of the course

C4.2: Propose one or more solutions answering the question rephrased in terms of value creation and complemented by the impact on other stakeholders and by taking into account other dimensions. Quantify the value created by these solutions. Arbitrate between possible solutions

3IF4230 – Databases for BigData

Instructors : **Francesca Bugiotti**
Department : **MENTION ARCHITECTURE DES SYSTÈMES INFORMATIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This class will focus on the Big-Data Storage Management Systems and the different query execution processes:

1) How the relational DBMS and the NoSQL systems store data
2) How the queries are translated in low-level operations that are executed on data physically stored according to the physical pattern of the system under analysis
3) How to write and re-write queries taking into account this physical organization for improving performances.

From the technology point of view:

Starting from the Relational databases we will see how an SQL query is translated in a query execution plan and how the table-size and
the operation that are expressed in the query influences the creation of this plan.

We will see how the same happens for graph databases (Neo4j) and other NoSQL databases.

Filally the Spark execution plan will be analyzed.

Thanks to the notions learnt in this class it will be possible to operate in the Big Data-context with the knowledge about how data are stored and manipulated by the DMBS.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Chapter 1. Introduction.
- Context.
- Relational databases and NoSQL systems.
- Notions of data distributions.

Chapter 2. RDBMS.
- Physical model of relational databases.
- Data storage.
- SQL query execution plan.
- Optimization of SQL queries.
- Join: an operation, multiple algorithms.

Chapter 3. NoSQL Systems.
- Analysis of new physical models.
- Architecture and queries.
- Data exploration

Chapter 4. Apache Spark.

- Data storage introduction.
- Execution plan of the operations.

Chapter 5. Apache Arrow.

- SIMD (Single instruction, multiple data) operations.
- Memory format.
- Vectorized optimization of analytical data processing.

Class components (lecture, labs, etc.)

Introduction. Lecture: 1,5h
RDBMS. Lecture: 6h, **Tutorial**: 3h
NoSQL Systems. **Lecture**: 3h
Apache Spark. Lecture: 3h, **Tutorial**: 3h
Apache Arrow. Lecture: 1,5h, **Tutorial**: 1,5h

Course 7,5h **tutorial**, 15h **lectures**

Grading

Control continu

Resources

Teaching staff: Francesca Bugiotti

Learning outcomes covered on the course

At the end of this course, the students must be able to:

- Understand the physical structures used by relational databases (RDBMS - Oracle, DB2, SQLServer, etc.) and NoSQL (HBASE, MongoDB, etc.).
- Be aware about how a query is translated and physically executed in the DBMS.
- Generalize the query execution workflow in distributed environments and platforms (Spark + Arrow).

Description of the skills acquired at the end of the course

C2 Acquire and develop in-depth expertise in a scientific or sectorial field and/or job.
C6 Thrive and innovative in the digital world.

- C6.5 Operate any type of data, structured or not, including large ones. Understand their transmission.

C8 Lead a team, manage a project.

- C8.1 Work collaboratively in a team.

3IF4240 – Web Software Architecture

Instructors : **Alexandre Blondin**
Department : **MENTION ARCHITECTURE DES SYSTÈMES INFORMATIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This elective has several objectives:

- Architecture: Know how the different web architectures work, their advantages, disadvantages and use cases
- Performance: Know how to monitor and solve the different web performance problems
- Security: Know the main vulnerabilities and how to protect yourself against them
- Quality: Know and apply the static and dynamic analysis tools that guarantee the quality of the code

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Course 1: Web architectures
- Chronological presentation of the different web architectures (SSG, SSR, SPAs, hybrids), with their comparative advantages
- Minimum implementation of each architecture

Course 2: Performance
- Decomposition of a performance analysis (TTFB, TTI)
- Review of solutions to tackle each performance problem
- Application of the analysis method to real sites, with review of potential solutions to implement to improve performance

Course 3: Security
- Security is of course not only a frontend topic, but our starting point will be the client browser.
- Review of the different security flaws: XSS, CORS,...
- Practical examples

Course 4: Static analysis
- Impossible to code professionally without a permanent static analysis of its code.
- This will be the occasion to talk about typing (TypeScript), linter, AST.
- Implementation of complex linter rules

Course 5: Dynamic analysis
- Brief review of the test pyramid.
- Presentation of less used tests: snapshot testing, visual testing, property-based testing, mutation testing

Class components (lecture, labs, etc.)

Alternating courses and case studies

Grading

Project

Resources

Teaching Staff : Alexandre Blondin

Learning outcomes covered on the course

Each course starts with theory, but the majority of the time will be devoted to practice: analysis of public websites, implementation by the students from real examples.

At the end of the course, students will have a solid theoretical base and will be able to implement the tools and methods discussed in the course on their future projects.

Description of the skills acquired at the end of the course

- C1.4 Design, detail and corroborate a whole or part of a complex system.
- C2.3 Rapidly identify and acquire the new knowledge and skills necessary in applicable/relevant domains, be they technical, economic, or others.

3IF4250 – Test Driven Developpment

Instructors : **Antoine Boileau, Laurent Cabaret**
Department : **MENTION ARCHITECTURE DES SYSTÈMES INFORMATIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course aims to provide students with an introduction to the notion of Test Driven Development and testable architecture.
While the TDD and architecture principles will be presented in their general framework, the course's end will open the door to applying these principles to a web server management application.
Three successive steps will allow the student to become competent:

- Principles and tools of the TDD methodology
- Further development of testable design
- Principles of abstraction, design, and architecture for designing robust applications.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Essential: Previous development experience

Syllabus

Principles and tools of the TDD methodology

- Test typology and TDD guideline
- Putting the TDD methodology into practice

Further development of testable design

- Dependency Management
- Code improvement during refactoring
- Toolbox for testing code despite itself

Principles of abstraction, design, and architecture for designing robust applications

- Importance of the business code and management of change and uncertainties
- Application to web architecture

Class components (lecture, labs, etc.)

Alternating courses and practical work allowing the assimilation and rapid implementation of concepts

Grading

- Multiple-choice question exam
- Team project defense

Resources

Teaching staff : Antoine Boileau

Learning outcomes covered on the course

By the end of this course, students will be able to :

- Understand and apply the principles and tools of the TDD methodology
- Implement abstraction, design, and architecture principles for the creation of robust applications

Description of the skills acquired at the end of the course

C2 Develop in-depth skills in an engineering field and a family of professions
C3 Act, undertake, innovate in a scientific and technological environment.

3IF4260 – High Performance Computing for Data Analysis

Instructors : **Stephane Vialle**
Department : **MENTION ARCHITECTURE DES SYSTÈMES INFORMATIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course proposes to study the "Spark" and "MPI" distributed programming environments, with sufficient depth for implementation on data analysis problems, with executions on PC clusters and with a "scaling up" approach. Labs with performance measurements and analysis will mark the course.

Quarter number

SG11

Prerequisites (in terms of CS courses)

- 1st year common course: Information Systems and Programming (1CC1000)
- 1st year common course: Algorithmic & Complexity (1CC2000)
- Course of 3rd year: Concurrent and Distributed Systems (3IF1040)
- Course of 3rd year: Hardware Architecture (3IF4010)

Syllabus

This course consists of 2 parts with Labs and a final written exam: Lectures 12h00, Labs 12h00 (total of 24 HPE)

- **Algorithmic and distributed programming with a "map-reduce" scheme in Spark:** Lectures 6h00, Labs 6h00
  - Spark RDD programming reminder
  - SQL concept and programming in Spark (*Spark-SQL*)
  - Concept and mechanisms for data flow processing in Spark (*Spark Structured Streaming)*
  - TPs on PC cluster in HDFS+Spark (Lab1.1: Spark-SQL, Lab1.2: TP Spark structured streaming)
- **Algorithmic and distributed programming by sending messages in MPI:** Lectures 6h00, Labs 6h00
  - Reminder of deployment of MPI+OpenMP code on multi-core PC clusters
  - Disk I/O from an MPI program
  - Distribution of a k-means clustering algorithm
  - Asynchronous communications, computations-communications overlapping
  - TPs of MPI on PC clusters (TP2.1: distributed k-means with mpi4py, TP2.2: matrix product with computation-communication overlap with C+MPI+OpenMP)

Class components (lecture, labs, etc.)

The concepts seen in the course will be implemented and deepened in 4 TPs. Each developed solution will be run on a PC cluster and its performance will be measured and analyzed. Optimizations of the codes and algorithms will be carried out if necessary to obtain solutions that can be "scaled up".

- Lectures: 12h00
- Labs on PC clusters, with reports and marks: 12h00

Grading

Valuation based on the MPI and Spark Labs:

- 50% : Reports of the TP parts 1
- 50% : Reports of the TP parts 2

Note: the content and the number of pages of the reports are constrained, in order to force the students to make an effort of synthesis and clarity

In case of unjustified absence from a TP the mark of 0 will be applied, in case of justified absence the mark of the final exam will be applied.

The make-up exam will be a 1 hour written or oral exam, which will constitute 100% of the make-up grade.

Resources

Teaching staff:

S. Vialle and **G. Quercini** (CentraleSupélec)

Computing resources :

the Labs will use the PC clusters of the Teaching Data Center of the Metz campus, accessed through the Internet.

Learning outcomes covered on the course

By the end of this course, students will know:

- **Learning Outcome 1 (AA1):** design and implement an MPI algorithm with data flow and collective communications,
- **Learning Outcome 2 (AA2):** design and implement an MPI algorithm with computation and communications overlay,
- **Learning Outcome 3 (AA3):** design and implement a Spark algorithm processing a data flow,
- **Learning Outcome 4 (AA4):** measure the performance and optimize Spark codes distributed on PC clusters,
- **Learning Outcome 5 (AA5):** test the ability of a code to "scale up".

Description of the skills acquired at the end of the course

- **C2:** Develop in-depth skills in an engineering field and a family of professions (in connection with learning outcomes AA1, AA2 and AA3).
- **C6:** Be operational, responsible, and innovative in the digital world (in connection with learning outcomes AA4 and AA5).
- **C7:** Know how to convince (in connection with the TP reports).

3IF4500 – InfoNum ASI Project

Instructors : **Laurent Cabaret**
Department : **MENTION ARCHITECTURE DES SYSTÈMES INFORMATIQUES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

The third year project allows students to apply their skills in an industrial or research project with the corresponding business constraints. In particular, it allows them to discover the different facets of the professions they will be able to carry out. These are the projects of the "Computer and Digital" major, including "Computer Systems Architecture", "Cybersecurity", "Artificial Intelligence" and "Software Science".

The objectives of the project are :

- The development of a "product" meeting the needs of a client (company, laboratory, association, students).
- The implementation of a rigorous methodology to go from the idea to the "product".
- The continuation of learning project management.
- Demonstrating the ability to present in writing and orally in a professional context.

Quarter number

SD9, SG10, SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Depending on the project. The projects can either be Dominant projects and thus cover themes developed in at least two of the dominant's mentions or they can be mention projects and thus address themes specific to one of the dominant's mentions.

Class components (lecture, labs, etc.)

Working in project mode.

Grading

The evaluation will be done by a mid-project point, and mainly by the final report, the final defense, and the opinion of the person in charge and client of the project. A jury, mobilized for the final defenses, will integrate these elements to evaluate the project as a whole.

Resources

- The projects take place in teams of 2 to 3 students.
- 200 hours are devoted to the projects.
- The supervision modalities depend on the type of project:
    - For CEI projects (industrial study contracts), supervision is shared between the industrialist and a teacher from the school who leads the students in their work.

    - For "Laboratories" projects proposed by a teacher, supervision is entirely provided by the teacher.
    - For all other types of projects (associations, partners, CPI), the supervision is mainly done by the person proposing the project (client), a teacher from the school ensuring the good progress of the project and the intermediate milestones.
- A mid-project point will be organised in December to ensure that the project is running smoothly.
- At the end of the project, a jury presentation will take place.

Learning outcomes covered on the course

By the end of the project, students will have learned :

- to work in teams outside the academic context
- to take into account the business constraints in the realization of a project
- manage uncertainty in the definition of expected results
- to present their project and results in a professional context

Description of the skills acquired at the end of the course

Working in teams outside the academic context is part of C8: "Leading a project, a team" and C5.2 "Listening, being understood and working with people from different cultures, backgrounds and skills".

Presenting one's project and results in a professional context is part of skill C7: "Knowing how to convince".

Taking business constraints into account in carrying out a project is part of C1: "Analysing, designing and building complex systems with scientific, technological, human and economic components", C2.3: "Identifying and rapidly acquiring the new knowledge and skills needed in the relevant fields, whether technical, economic or other", and C4: "Having a sense of value creation for one's company and one's customer".

Managing uncertainty in the definition of expected results is part of C3.4: "Making decisions in a partially known environment, managing the unexpected, knowing how to take risks" and C3.7: "Choosing solutions and acting pragmatically, with a view to obtaining tangible results".

Competencies C9: "Act as a responsible professional. Think, act ethically" and C6: "Be comfortable and innovative in the digital world" can also be mobilized.

3IF5010 – Reverse engineering, Virology

Instructors : **Jean-Francois Lalande**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **45**
On-site hours (HPE) : **24,00**

Description

The objectives of this module are to present the skills needed to understand malware targeting Windows and Android platforms.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

When a security analyst must consider the scope of a malicious code, he or she must be able to quickly understand the purpose of the attack (the payload) and the means of attack (the exploited vulnerabilities). To do this, the analyst generally does not have the source code but the binary code or byte code. The module is therefore organized around two main activities: reverse engineering of the code (disassembly, decompilation, representation in intermediate form) and malicious code analysis: location of the payload, static and dynamic analysis. The participants of this course will be led to analyze malicious code themselves (real code but previously neutralized).

Virology x86

- CM 2h assembly
- Lab 1h assembly
- CM Reverse 3h
- CM Malware 3h
- Lab Reverse of malwre x86 6h

Android virology

- CM 3h Reverse Android
- Lab 3h Reverse Android

Class components (lecture, labs, etc.)

Courses and labs.

Grading

- 50% Lab Reverse of malwre x86
- 50% Lab Reverse Android

Resources

Courses and practical sessions on real malware (but neutralized).

Learning outcomes covered on the course

Reverse engineering of x86 code, reverse engineering and analysis of malicious Android code, expertise in the challenges and difficulties of threat analysis.

Description of the skills acquired at the end of the course

C2 - Acquire and broaden thorough expertise in an area of scientific and academic knowledge, as well as applied professional areas.

3IF5020 – Introduction to memory attacks

Instructors : **Pierre Wilke**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **45**
On-site hours (HPE) : **24,00**

Description

In this course, we focus on a broad class of attacks, namely those related to memory corruption.
These attacks are largely due to programming errors during manual memory management in programming languages such as C and C++.
They are one of the main sources of vulnerabilities exploited by attackers for at least 30 years.
The lack of a security around memory management leaves the field open for attackers to divert the delivery of vulnerable programmes to them.
A very large number of solutions to these problems have been proposed, but none of them has yet made it possible to completely stop the flow of attacks based on this class of vulnerabilities.

Quarter number

SG10

Prerequisites (in terms of CS courses)

In order to take this course profitably, you need to have taken:

- an x86 assembler course;
- a C language course;
- and a operating systems courses

beforehand.
Ideally, a compilation course allows for a better understanding of the security issues related to manual memory manipulation, as well as the possible countermeasures at the compiler level.

Syllabus

This course is organized as follows

- Introduction.
- Brief reminders of the supposedly acquired knowledge (C, assembler, operating systems)
- Study of a code with a coarse programming error (stack overflow):
  - Study of binary code
  - Dynamic analysis at the debugger.
- Study of a code modifying itself its return address:
  - Study of the binary code.
  - Dynamic analysis in the debugger.
- General principle of a memory overflow attack on the stack.
- Designing an offensive load for a stack overflow attack.
- Review of major countermeasures:
  - Strict protection of the different memory areas (code, heap, stack, libraries).
  - Randomization of virtual address spaces.
  - Use of a canary.
  - Intelligent placement of variables in the stack.
- Some elements on more elaborate attacks.

The practical sessions are devoted to a simulation of the situation to apply this knowledge to an attack targeting a server running an unknown protocol accessible through the network.

Class components (lecture, labs, etc.)

Lectures: 9h
Labs: 15h

Grading

The module will be evaluated by a situation scenario leading to the analysis of an attack on an unknown information system via the remote exploitation of a vulnerable service.
This simulation will take place during practical sessions.
The practical work will be evaluated by a presentation.

Final exam: oral presentation by groups of 2.

The oral exam will allow to validate skills C2 (for the technical part of the work done) and C7 (for the quality of the presentation)

Course support, bibliography

One, Aleph. "Smashing the Stack for Fun and Profit." *Phrack* 7 , no. 49 (1996)

Resources

Teachers: Frédéric Tronel and Pierre Wilke
Softwares: Virtualbox, a compilation chain (gcc and gdb).

Learning outcomes covered on the course

- Auditing C source code for memory manipulation errors (buffer overflow, double free, use after free, format strings, ...).
- Debugging a binary code using a debugger in order to track down memory handling errors (display source code, assembler code, display processor registers, run the code in step-by-step mode, know how to set a breakpoint, know how to set an observation point, ...).
- Audit the operation of an unknown binary code using specialized tools (like Valgrind for example).
- Collect compromise indicators on an unknown information system (network trace, exploration of system logs, audit of configuration files).
- Analyze an offensive load from its binary code.

Description of the skills acquired at the end of the course

C2.5
C7.4

3IF5030 – Cryptography 2

Instructors : **Christophe Bidan**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **35**
On-site hours (HPE) : **18,00**

Description

Cryptography is a set of techniques that make it possible to ensure the security properties of a system, in particular the data confidentiality, the data integrity and the data authenticity. These techniques are based on mathematical foundations, but are implemented using algorithms (e.g. encryption and decryption primitives) and cryptographic protocols (how to carry out exchanges in a secure manner). This second part of the course is dedicated to cryptographic protocols, and to side channel attacks.

Quarter number

SG10

Prerequisites (in terms of CS courses)

- First year courses : SIP, Algorithms, Networks and security
- Third year courses : Crypto 1

Syllabus

- Lecture 1 (3h) - Cryptographic protocols : authentication, key exchange, key agreement, secure channel
- Lecture 2 (3h) - Examples of cryptographic protocols : Diffie-Helmann, TLS, IPSEC ...
- PW 1 (3h) - On using TLS
- PW 2 (3h) - On using IPSEC.
- Lecture 3 (3h) - Side channel attacks.
- PW 3 (3h) - Simple and differential power analysis.

Class components (lecture, labs, etc.)

Lecturers (9h) and pratical works (9h)

Resources

Teachers :

- Christophe BIDAN (CentraleSupélec).
- Ronan LASHERMES (Inria)

Learning outcomes covered on the course

At the end of this course, students will be able to :

- Analyze cryptographic protocols to ensure that they provide the required security properties,
- Use appropriate cryptographic protocols to ensure the required security properties,
- Understand the risks associated with side channel attacks.

Description of the skills acquired at the end of the course

C2.1 - Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.

3IF5050 – Advanced Memory Attack Techniques

Instructors : **Pierre Wilke**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **40**
On-site hours (HPE) : **18,00**

Description

In this course we focus on a broad class of attacks, namely those related to memory corruptions.
We try to cover all the techniques developed by attackers to exploit these vulnerabilities.
We also cover all the state-of-the-art countermeasures used to fight against these vulnerabilities.

Quarter number

SG10

Prerequisites (in terms of CS courses)

In order to follow this course profitably, it is mandatory to have followed the first part of the course devoted to basic attacks against memory.
It is also useful to have followed a compiler course in order to understand the countermeasures implemented at the compiler level.

Syllabus

This course begins by reviewing the different methods to exploit vulnerabilities related to memory manipulation errors.
For each vulnerability category, we illustrate the programming fault that caused it, and how the error it may induce at execution time propagates to the point of allowing an attacker to exploit the vulnerability:

- Format string errors.
- Errors related to integer overflows and their link with memory management errors (integer overflow).
- Heap overflow:
  - Study of heap structure under Linux: dlmalloc and ptmalloc algorithms; exploitation of programming errors in heap allocations.
  - Study of heap structure under Windows; exploitation of heap overflow programming errors.
- Most common countermeasures in operating systems: address space randomization and policy enforcement of memory areas rights (ASLR and NX bit).
- Bypassing conventional countermeasures:
  - Return to the C library (Ret-to-libc): introduction of the concept and example of use.
  - Return Oriented Programming (ROP): introduction of the concept and operating example.
  - Gadget discovery tools for ROP.
  - Diversion of execution to on-the-fly compiled code areas: JIT and Heap spraying.
- Type confusion in "secure" languages:
  - pointer table in object-oriented or prototype-oriented languages
  - principle of type confusion in typed languages (dynamically or statically)
- Study of binary formats:
  - ELF binary file format:
    - Header, role of sections and segments.
    - Handling of relocations (relocations).
    - Operation of the loader (ld.so). Link with the implementation of address space randomization and the application of a strict right policy on the various memory areas.

        - Dynamic resolution of symbols by the dynamic link editor (ld.so). Link with the implementation of randomization of the address space. Operation of the .got and .plt sections.
        - System calls and VDSO.
        - Diversion of the execution flow via GOT and PLT.
        - Compilation countermeasures.
    - PE binary file format:
        - Header and role of the import and export tables.
        - Operation of the loader and dynamic link editor.
        - Randomization of the address space
- Countermeasures:
    - Control Flow Integrity via the compiler.
    - Data Flow Integrity via the compiler.
    - Protection of pointers (e.g. Cheri) via hardware.
    - Intel CET

Class components (lecture, labs, etc.)

Lectures: 9h
Labs: 15h

Grading

The module will be evaluated via a situation analysis leading to the analysis of an attack on an information system via the remote exploitation of a vulnerable service. The payload used by the attacker will be able to override several security countermeasures put in place on the system. Its analysis will allow to illustrate the different concepts seen during the course. This simulation is will take place during lab sessions. The lab sessions will be evaluated by an oral presentation.

CF: oral presentation
The oral presentation will allow to validate skill C2 (technical part) and C7 (quality of oral presentation)

Course support, bibliography

- Solar Designer, "Return-into-lib(c) exploits" sur seclists.org, août 1997
- Nergal, "The advanced return-into-lib(c) exploits", Phrack, n°58, 2001
- Sebastian Krahmer, "x86-64 buffer overflow exploits and the borrowed code chunks exploitation technique", septembre 2005
- Jonathan Salwan et Allan Wirth, "ROPgadget, Gadgets finder and auto-roper"
- Laszlo Szekeres, Mathias Payer, Tao Wei, Dawn Song, "SoK: Eternal War in Memory", Proc. of the 2013 IEEE Symposium on Security and Privacy

Resources

Teachers: Frédéric Tronel and Pierre Wilke

Learning outcomes covered on the course

- Audit a source code written in C or C++ to find vulnerabilities belonging to the different classes of attacks related to manual memory manipulation.
- Audit an advanced malicious payload.
- Audit the configuration of an operating system and its compilation chain in order to qualify its robustness.

Description of the skills acquired at the end of the course

C2.3
C7.1

3IF5060 – Functional Programming and Software Security

Instructors : **Pierre Wilke**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

In order to secure a whole system, one needs to secure each of its components : the hardware, the Operating System, the applications that are executed. This course focuses on the latter : securing programs.

For critical systems, it is important to have a great confidence in our programs. To that end, we will study the notion of programming languages semantics, and Hoare logic, which allows to reason about the behaviour of programs. We will also study the basics of static analysis, which allows to compute automatically correct information about programs, without executing them. Finally, we will focus on verified compilation, which allows to bring the safety properties of a source program down to a compiled program.

These notions will be illustrated within the Coq proof assistant.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

Semantics of programming languages
Safety and security properties
Static Analysis - Abstract Interpretation
Program proofs - Hoare Logic
Formal proofs (Coq)

Class components (lecture, labs, etc.)

- Lectures : 12h
- Labs : 18h

Grading

- Lab report
Skill C1 is validated by the validation of the report.

Course support, bibliography

Software Foundations, Benjamin Pierce et al. https://softwarefoundations.cis.upenn.edu/lf-current/index.html
Certified Programming with Dependent Types, Adam Chlipala, http://adam.chlipala.net/cpdt/
Patrick Cousot, Radhia Cousot: Abstract Interpretation: A Unified Lattice Model for Static Analysis of Programs by Construction or Approximation of Fixpoints. POPL 1977
C. A. R. Hoare. "An axiomatic basis for computer programming". Communications of the ACM, 1969

Resources

Teacher: Pierre Wilke
Maximum number of students : 35
Software : Coq (free, no licence necessary)
Level 5 lab rooms (Rennes)

Learning outcomes covered on the course

Understand and define the semantics of a programming language.
State security and safety properties on a program.
Design a static analysis.
Write formal proofs.

Description of the skills acquired at the end of the course

C1.4 Design, detail and corroborate a whole or part of a complex system.

3IF5210 – Operating system security

Instructors : **Guillaume Hiet**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **36,00**

Description

Operating systems provide an interface between the hardware and the applications launched by users.

Applications with different sensitivity and trust levels may be executed simultaneously on the same system, and it is crucial for the OS to provide security mechanisms ensuring some form of isolation between those applications, while still allowing legitimate communications between them.

Operating systems like Linux, Mac OS or Windows provide some security mechanisms that we will study.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Information Systems and Programming (SIP)
Algorithms and Complexity
Network and Security
Operating Systems

Syllabus

- Introduction, approach to securing operating systems
- System and boot integrity
- Partition encryption and file systems
- Authentication and management of users
- Access control
- Isolation and Mandatory Access Control
- Secured administration

Class components (lecture, labs, etc.)

- Lectures (15 x 1h30)
- Labs (3 x 3h)

Grading

Final oral exam (lab defense + questions)

Course support, bibliography

- Lecture slides (PDF files available on Edunao)
- Introducing Windows Server 2012, Mitch Tulloch with the Windows ServerTeam, Microsoft Press.
- Active Directory, Brian Desmond, Joe Richards, Robbie Allen, Alistair G.Lowe-Norris, Fourth Ed., O'Reilly Media Inc.
- Linux Administration - Tome 3 : Sécuriser un serveur Linux, Jean-François Bouchaudy, Eyrolles

Resources

- Teachers : Guillaume Hiet, Frédéric Tronel, Jean-François Lalande
- Number of students : 35
- Software and licences : VirtualBox, Microsoft Windows images (36 licences)
- Lab rooms : Rennes campus, level 5 (1x35 or 2x18)

Learning outcomes covered on the course

At the end of this course, students will be able to

- assess the security of an operating system
- set up different security mechanisms (Linux and Windows)

Description of the skills acquired at the end of the course

C2 - Analyse, design and implement complex systems made up of scientific, technological, social and economic dimension

C7 - Strengthen the Art of Persuasion

3IF5220 – Web development and security

Instructors : **Pierre-François Gimenez**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **30,00**

Description

Web applications have become a major development and programmation paradigm, often playing a central part in modern information systems. From an information security point of view, they also are the most significant source of vulnerabilities and the most common entry point for an attacker. The aim of this course is to provide basic web development skills, a synthetic vision of architectural and functional principles of modern web applications and an insight of a few popular development technologies. On these foundations, we introduce the security concerns specific to web applications, in a manner both theoretic and experimental, in order to acquire the skills and tools necessary for evaluating the security of web applications. A significant development project, in a technology chosen by students, will allow them to confront the issues of secure web application development.

Quarter number

SG11

Prerequisites (in terms of CS courses)

First year courses:
- Networks and Security.

Third year courses:
- Programmation workshop and development tools;
- Introduction to Security;
- Cryptography 1.

Syllabus

- Lecture 1 (3h): Introduction, modern architectures for web applications
- Lecture 2 (3h): JavaScript
- Lab 1 (3h): JavaScript frameworks (Angular, Node.js)
- Lecture 3 (3h): React
- Lecture 4 (3h): A Python-based server-side development framework: Flask
- Lab 2 (3h): Flask + React
- Lecture 5 (3h): Web application security
- Lecture 6 (3h): Security - business logic vulnerabilities
- Lecture 7 (3h): Sécurité - client-side vulnerabilities
- Lecture 8 (3h): Sécurité - server-side vulnerabilities
- Lecture 9 (3h): Sécurité - chained vulnerabilities
- Lab 3 (3h): Development project
- Lab 4 (3h): Development project
- Lab 5 (3h): Development project

Class components (lecture, labs, etc.)

Lectures : 27h
Lab sessions : 15h

Grading

Evaluation of a secure web application development project.

Resources

Software tools:

- Common web development environments;
- Burp Suite Community Edition;
- Dedicated web security challenge platform for lab sessions.

Learning outcomes covered on the course

At the end of this course, students will be able to:

- Design and develop modern web applications involving both server-side and client-side processing;
- Foresee security risks during the design of web applications;
- Evaluate the security of a web application by using appropriate tools and methodologies;
- Perform web penetration testing activities;
- Advise web architects and developers regarding the improvement of their products' security.

Description of the skills acquired at the end of the course

- C4.2 Propose one or more solutions that answer the question reformulated in terms of value creation and complete by taking into account the impact on the other stakeholders and by taking into account the other dimensions. Quantify the value created by these solutions. Arbitrate between possible solutions
- C7.1 Substance: Structure ideas and arguments, summarise (hypotheses, objectives, expected results, approach and value created).
- C8.1 Build a team to work as a team

3IF5230 – Audit - Pentest

Instructors : **Jean-Francois Lalande**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **70**
On-site hours (HPE) : **42,00**

Description

This course allows students to discover the audit en pentest activities. These activities are specific to this kind of job and consist in evaluating the security of a system by trying to penetrate a real deployed system. The audit part is complementary to the pentest activity. The auditer study the defense mecanisms that a system has setup to prevent any abuse.
From the point of view of the course, the pentest and audit activities need all the previous modules that concern security. Focused on practice, the audit and pentest will be conducted by indurstials of the domaine, which will allow to work on real use cases (Windows or Linux systems, embedded systems).
A summary course will introduce the basics (vocabulary, methodology).

Quarter number

SG11

Prerequisites (in terms of CS courses)

Introduction to security
Cryptography 1 & 2
Security of operating systems
Network security (Infosec) or Operating systems (dominante)

Syllabus

- Introduction course (vocabulary, methods)
- Airbus challenge: intrusion in an industrial system
- Cogiceo challenge: pentest agains an Active directory
- Wavestone challenge: CTF
- Challenge Enedis

Class components (lecture, labs, etc.)

Challenge

Grading

Evaluation of the results of challenges

Resources

Capture the flags, simulations

Learning outcomes covered on the course

- perform intrusion tests against real systems
- achieve cyber attacks
- evaluate defenses

Description of the skills acquired at the end of the course

C1 - Analyse, design and implement complex systems made up of scientific, technological, social and economic dimension
C9 - Think and act as an accountable ethical professional

3IF5240 – Secure Development

Instructors : **Pierre Wilke**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**
Elective category :
Advanced level :

Description

Software security is often not taken into account during the development of applications.
However, it is possible -- and desirable -- to make specification and design choices that increase the security of the software.
Some programming practices allow to implement security concepts such as authentication, encapsulation, exception handling, etc.
The objective of this course is to introduce the various security concepts that are either integrated into programming languages, or that are to be reconstructed in the language.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Compilation
Operating systems
Modeling and design of a system of sensors supervision

Syllabus

- Design patterns for security
- Design patterns for the implementation of security
- Applicative security in Java
- Implementation of security in the Spring framework
- Static analysis of C code with Frama-C

Class components (lecture, labs, etc.)

Lectures 6h
Labs 6h

Grading

2 lab reports (1 lab on Spring, 1 lab on static analysis)
Skill C6 is validated by a grade above or equal to 10 for all lab reports.

Course support, bibliography

The Cybersecurity Body of Knowledge: The ACM/IEEE/AIS/IFIP Recommendations for a Complete Curriculum in Cybersecurity (Internal Audit and IT Audit) 1st Edition
by Daniel Shoemaker (Author), Anne Kohnke (Author), Ken Sigler (Author)

Resources

Teachers : Jean-François Lalande, Pierre Wilke

Learning outcomes covered on the course

Develop secure software
Choose the appropriate language for given security needs
Test an already written piece of software
Know identity management and authentication protocols

Description of the skills acquired at the end of the course

C6.3 : software specification, design and validation

3IF5500 – Infonum CyberSec Project

Instructors : **Jean-Francois Lalande**
Department : **MENTION CYBER SÉCURITÉ (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

The security project put into practice the knowledges and core skills of the option. It answers to a request of a partner, or an external industrial or an academic researcher.

Quarter number

SD9 SG10 SG11

Prerequisites (in terms of CS courses)

All modules of the option.

Syllabus

- Subject choice
- Project development
- Audition and report

Class components (lecture, labs, etc.)

Project pedagogy.

Grading

Audition and report.

Resources

Project with a supervisor.

Learning outcomes covered on the course

C1, C2, C6, C3, C4, C7, C8, C9

Description of the skills acquired at the end of the course

C1, C2, C6, C3, C4, C7, C8, C9

MATHEMATICS AND DATA SCIENCE MAJOR (MDS)

3MD1010 – Machine learning

Instructors : **Arthur Tenenhaus, Emilie Chouzenoux, Frederic Pascal, Pauline Lafitte**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Technological developments are leading to increasingly large data acquisitions (signals, images, measurement results, etc.) that require the use of techniques that allow useful knowledge to be extracted. Classification and machine learning, which seek to transform raw data into more structured knowledge, provide tools adapted to this type of problem.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Level: standard (ML-B)
Statistics and Learning
Optimization

Level: advanced (ML-A)
- linear algebra
- functional analysis.
- basic probabilities concepts
- foundations of machine learning concepts (2nd year elective course, césure internship, and so on)

Moreover, the students must be familiar with Python programming.

Syllabus

Level: standard (ML-B)

- Supervised Learning and empirical risk minimization
  1. Regression and classification (Ridge Regression, Generalized Linear Model -including logistic regression, Support Vector Machines). Extensions to kernel methods
  2. Generalized Linear Models and variable selection (sparsity constraints)
  3. Aggregation methods (Random forest, Boosting)
- Unsupervised learning
  1. Mixture model
  2. Dimension reduction (Principal Component Analysis, tSNE)
  3. K-means / Hierarchical clustering

The methods described in the course will be implemented during Practical Works (through R or Python language).

Level: advanced (ML-A)

1. Reminders on ML and Bayesian theory
2. Robust regression approaches
3. Stochastic approximation algorithms
4. Hierarchical clustering
5. Nonnegative matrix factorization
6. Mixture models fitting

7. Model order selection
8. Inference on graphical models

Class components (lecture, labs, etc.)

Level: standard (ML-B)
Lectures. Each lecture will include practical session in R or Python.

Level: advanced (ML-A)
Each section of the course is divided into 1h30' lecture and 1h30' lab. The labs will include exercises and practical session in python.

Grading

Level: standard (ML-B)
Homework and Data Challenge

Level: advanced (ML-A)
- Written exam: the exam will include theoretical questions related to the course, as well as the study of a research paper.

- Labs reports: The students are expected to submit an individual for 3 of the lab sessions.

The grading will be as follows:

Exam 50%
Lab reports 50%

Course support, bibliography

Level 1 (ML-B)
[1] T. Hastie, R. Tibshirani, et J. Friedman, "The Elements of Statistical Learning: Data Mining, Inference and Prediction", Springer, 2001.
[2] R. Duda, P. Hart, et D. Stork, "Pattern classification", John Wiley, 2001.
Level 2 (ML-A)
James, G., Witten, D., Hastie, T. and Tibshirani, R. (2013) An Introduction to Statistical Learning, with Applications in R. Springer.
Hastie, T., Tibshirani, R. and Friedman, J. (2009) The Elements of Statistical Learning: Data Mining, Inference, and Prediction. Second edition. Springer.
C. M. Bishop (2006). Pattern Recognition and Machine Learning. Springer.

Resources

Teaching teams: Arthur Tenenhaus and Hani Hamdan [standard level, ML-B] / Emilie Chouzenoux, Frédéric Pascal [advanced level, ML-A]

Learning outcomes covered on the course

Overview of machine learning and classification methods as well as application examples of the different approaches developed.

Description of the skills acquired at the end of the course

At the end of this course, students will be able to understand and choose machine learning method and implement it, in line with the problem.

3MD1020 – Optimization

Instructors : **Vincent Lescarret**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **46**
On-site hours (HPE) : **24,00**

Description

Optimization is the field of study of minimizing or maximizing a criterion with real values. For continuous optimization, the criterion is defined on a closed, non-empty interior set. For discrete optimization, the criterion is defined on a finite or countable set.
The objective of this course is first of all to present the formal framework of optimization problems and to study the questions of existence and uniqueness, characterization of solutions and numerical methods.

Prerequisites (in terms of CS courses)

Differential calculus

Syllabus

- Optimization problems, Existence and uniqueness,
- Optimization under constraints: Lagrange multipliers
- Lagrangian and duality, KKT theorem
- Uzawa algorithm
- Discrete optimization in linear programming, simplex algorithm

Class components (lecture, labs, etc.)

Lectures, tutorials and practical labs (3h) with python.

Grading

Written exam (3h) + marked labs

Course support, bibliography

[1] Optimisation et contrôle, Grégoire ALLAIRE, Alexandre ERN, Ecole Polytechnique, http://www.cmap.polytechnique.fr/~allaire/map435/poly435.pdf

Resources

Teaching team: V. Lescarret

Learning outcomes covered on the course

Several numerical methods will be presented. For continuous optimization, these methods will concern the search for local or global optima, with or without constraints. For discrete optimization, these methods can be exact or approximated.

Description of the skills acquired at the end of the course

The main skills developped in the lecture include the ability to decide the existence and uniqueness or non uniqueness of solutions to minimisation problems as well as to write their abstract mathematical characterization and apply a few standard numerical methods.

3MD1030 – Stochastic Integration

Instructors : **Sarah Lemler, Pauline Lafitte, Hana Baili**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course contains an introduction to stochastic calculus useful for studying time-dependent random phenomena. What is commonly called stochastic calculus consists of the theory of stochastic integrals and the rules of calculation that govern the use of these integrals.

Quarter number

SD9

Prerequisites (in terms of CS courses)

first-year probability courses [standard level] / advanced probability courses (Gaussian process, conditional expectation, downtime, martingale) [advanced level].

Syllabus

A few reminders on stochastic processes.
Filtration.
Stopping time.
Conditional expectation.
Martingales.
Brownian movement.
Construction of stochastic integral.
Itô's formula.
Girsanov's theorem.
Stochastic differential equations.

Class components (lecture, labs, etc.)

Lectures, tutorials.

Grading

Written exam (3h).

Course support, bibliography

P. Protter (2005), "Stochastic Integration and Differential Equations", Springer, 2nd edition.
B. Øksendal (2003), "Stochastic Differential Equations: An Introduction with Applications", Springer, 6th edition.
J.-F. Le Gall, "Mouvement brownien et calcul stochastique", Notes de cours de DEA 1996-1997, Université Pierre et Marie Curie.
J. Jacod, "Mouvement brownien et calcul stochastique", Notes de cours de DEA 2007-2008, Université Pierre et Marie Curie.

Resources

Teaching team: Hana Baili [standard level] / Sarah Lemler [advanced level]

Learning outcomes covered on the course

Theory of stochastic integrals and Itô’s formula

Description of the skills acquired at the end of the course

By the end of this course, students will be able to :
- understand the mechanisms of the construction of a stochastic integral; in particular, they will see the difference from classical integration in Lebesgue's sense;
- to manipulate the semimartingales and in particular the processes of diffusion via Itô's formula.

3MD1040 – Statistics

Instructors : **Sarah Lemler, Pauline Lafitte, Gilles Faÿ**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Stat A: In this theoretical course, we'll focus on high-dimensional estimation (when the number of explanatory variables exceeds the number of observations) using regularized methods in regression models (linear, nonlinear, generalized linear). We will study the theoretical guarantees of the Lasso estimator in these different models. Finally, we present variants of Lasso adapted to different application cases.

Stat B: In this course, which is more methodological than theoretical, we propose a few extensions to the 1st year course, namlely: Non-parametric density estimation, resampling methods, non-parametric regression.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Students must have a good knowledge of basic probability concepts and statistical concepts.

Stat A: Students should have seen the following concepts:
- linear regression model
- parametric and non-parametric estimation (maximum likelihood estimator, least squares estimator, study of the risk of an estimator)

Stat B: Students must have completed an introductory course in statistics, including notions of statistical models, estimators and testing, such as the first-year "Statistics and Learning" course.

Syllabus

Stat A:
- Penalized methods
- Theoretical study of the Lasso in the linear regression model
- Theoretical study of the Lasso in the non-linear regression model
- Generalized linear model and the Lasso
- Lasso variants

Stat B:
- Introduction and reminders
- Non-parametric estimation of a distribution (Glivenko-Cantelli, histograms and kernel estimators, bandwidth selection, cross-validation)
- Bootstrap method (rationale and some boostrap estimates)
- Linear regression (reminders)
- Non-parametric regression (kernel estimate, projection estimates, cross-validation)

Class components (lecture, labs, etc.)

Course notes, as well as the subjects and solutions of the lab sessions, are available on the websites of the teaching staff (Edunao).

The course is organized in 7 sessions of 3 hours each, the sessions being generally composed of 1,5hr of lecture in the amphitheatre and 1,5hr of lab session in small groups.

For Stat B: Lab sessions may include a numerical part, requiring a personal computer with R software installed.

Grading

Students' knowledge acquired during this course will be evaluated by a written exam, including problems and questions related to the course.

Resources

Teaching team: Sarah Lemler (Stat A) and Gilles Faÿ (Stat B)

Learning outcomes covered on the course

At the end of the course, students should be able to apply the statistical methods studied, knowing their limits and the theoretical guarantees concerning them.

Description of the skills acquired at the end of the course

It is expected that by the end of the course, students will be able to apply advanced statistical methods/tools in applications with real data, while understanding their theoretical underpinnings, their theoretical guarantees, and their limits.

3MD1050 – Harmonic analysis

Instructors : **Pauline Lafitte, Laurent Moonens**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course aims at presenting some important harmonic analysis techniques that can be used in several application areas (P.D.E. analysis, geometric measure theory, etc.).

Quarter number

SD9

Prerequisites (in terms of CS courses)

A good knowledge of real analysis and the basics of "Hilbertian" Fourier analysis.

Syllabus

The course will be structured as follows:

Theoretical part:

1. Fourier Transform (discrete and continuous), Poisson kernel, extension to tempered distributions.
2. Coverings and maximal functions; Stein principles. Applications to almost everywhere convergence (of processes, averages, Fourier partial sums).
3. Calderón-Zygmund decompositions; application to almost everywhere convergence.

If time permits, various aspects of the Stokes formula (Gauss-Green's theorem, or divergence).

Applicative part:

a number of applications of harmonic analysis will be presented in the context of computer science. In particular the following ideas will be discussed:
1. Signal processing and filtering.
2. Representation for Machine Learning.
3. Data compression (JPEG, MP3).
4. Computational imaging (MRI, Earth-sized computational telescopes).

Additionally, a lab session (1h30) will follow in which a demonstration of how the Fourier transform can be utilized for a signal processing (audio, image). For the lab the students will need to have their personal laptops, python will be used within the google colab platform.

Class components (lecture, labs, etc.)

Theoretical part: Lectures. In addition to the lecture sessions, suggestions for exercises will be made regularly.

Applicative part: Lecture + lab.

Grading

Written exam (3h).

Course support, bibliography

L.C. Evans et R. Gariepy, *Measure theory and fine properties of functions*, CRC Press.
A. Garsia, *Topics in almost everywhere convergence*, Markham Publishing Company.
P. Mattila, *Geometry of sets and measures in Euclidean spaces*, Cambridge.
M. Willem, *Analyse harmonique réelle*, Hermann.

Resources

Teaching team: Laurent Moonens, Laboratoire de Mathématiques d'Orsay (theoretical part), Stergios Christodoulidis, CS (applied part)

Learning outcomes covered on the course

Advanced function decomposition techniques.

Description of the skills acquired at the end of the course

A mastery of the techniques studied in order to be able to use them in other parts of the analysis.

3MD1060 – Big Data Parallel Processing Infrastructure

Instructors : **Gianluca Quercini**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course aims to introduce the main technologies to deal with the many challenges posed by Big Data.

Big Data is a term used to describe huge collections of data that grow exponentially over time. In short, this data is so large and complex that none of the traditional data management tools are capable of storing or processing it efficiently.

This course introduces existing technologies that make efficient processing of large volumes of data possible, namely Hadoop MapReduce and Apache Spark.

Quarter number

SD9

Prerequisites (in terms of CS courses)

- Python programming
- Relational databases basic notions.

Syllabus

MapReduce programming
- Introduction to MapReduce: motivations and examples.
- Implementation of MapReduce.

Hadoop
- Introduction to Hadoop and its features.
- Hadoop Distributed File System (HDFS)

Introduction to Apache Spark
- Introduction to Spark and its functionalities (RDD, transformations, actions, dataframes, datasets).
- Spark architecture and execution model.
- Implementation of Apache Spark.

Components of Apache Spark
- SparkSQL, Spark Streaming, Machine learning and graph analysis.

Grading

A 3hr written exam and 1 graded lab

Course support, bibliography

• Teacher's slides.

• Singh, Chanchal, and Manish Kumar.Mastering Hadoop 3: Big data processing at scale to unlock unique business insights. Packt Publishing Ltd, 2019.
• Mehrotra, Shrey, and Akash Grade.Apache Spark Quick Start Guide: Quickly learn the art of writing efficient big data applications with Apache Spark. Packt Publishing Ltd, 2019.
• Karau, Holden, et al.Learning spark: lightning-fast big data analysis. " O'Reilly Media, Inc.", 2015.

Resources

Teaching team: Gianluca Quercini

Learning outcomes covered on the course

- Understand the concepts behind Big Data.
- Use distributed computing paradigms: MapReduce and Spark.
- Design algorithms for distributed computing on data.

Description of the skills acquired at the end of the course

Exploit any type of data, structured or not, including massive data.

3MD1070 – Time Series

Instructors : **Pascal Bondon, Pauline Lafitte**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This time series course aims to present parametric models of observation series and their applications to the analysis and forecasting of sequentially observed data over time. We consider in detail the short-memory autoregressive moving average (ARMA) model, the long-memory autoregressive fractional moving average (ARFIMA) model, as well as nonlinear models used in the analysis of financial series such as the conditionally heteroscedastic autoregressive (ARCH) model and its generalizations. Finally, we introduce the integer-valued autoregressive (INAR) model for the time-correlated counting series. The course is illustrated with examples of real time series modeling using R software.

Prerequisites (in terms of CS courses)

Convergence Integration Probabilities ; Statistics and learning.

Syllabus

1. Second order stationary time series: covariance function and spectral measure, linear process, time and frequency domains.
2. ARMA process: existence, stationarity, causality, inversibility, seasonal ARIMA time series, long memory time series.
3. Linear prediction: prediction equations, recursive methods for computing linear predictors, infinite past linear prediction, Kolmogorov's formula.
4. Estimation of the mean and the covariance: strict stationarity and ergodicity, limit theorems, Bartlett's formula.
5. Estimation for ARMA models: preliminary estimation, Gaussian maximum likelihood estimation, least squares estimation, asymptotic properties of estimators, examples.
6. Conditionally heteroskedastic models: ARCH and GARCH models, stochastic volatility models, long-memory models.
7. Counting time series models : properties, estimation and prediction of INAR and INGARCH models.

Class components (lecture, labs, etc.)

Lectures and practical labs.

Grading

Written exam (2h) and lab reports.

Course support, bibliography

P. J. Brockwell and R. A. Davis. Time Series : Theory and Methods. Springer Verlag, New York, second edition, 1991.
J. D. Cryer and K. S. Chan, Time Series Analysis with Applications in R. Springer Verlag, New York, second edition, 2008.
C. Francq and J.-M. Zakoïan. GARCH models. Structure, Statistical Inference and Financial Applications. Hoboken, NJ : John Wiley & Sons, 2nd edition edition, 2019.
W. A. Fuller. Introduction to Statistical Time Series. Wiley, New York, second edition, 1995.
R. H. Shumway and D. S. Stoffer, Time Series Analysis and Its Applications with R Examples, Springer

Verlag, New York, second edition, 2005.
R. S. Tsay. Analysis of Financial Time Series. Wiley Series in Probability and Statistics : Probability and Statistics. Wiley-Interscience, New York, 2001.
C. H. Weiss. An introduction to discrete-valued time series. Hoboken, NJ : John Wiley & Sons, 2018.

Resources

Teaching team: Pascal Bondon, CNRS, L2S (class)

Learning outcomes covered on the course

Parametric models of observation series and their applications to the analysis and prediction of time-sequential observed data.

Description of the skills acquired at the end of the course

Knowledge of the selection of advanced statistical methods relevant to time series.

3MD1080 – C++

Instructors : **Dominique Marcadet**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

C++ is a language allowing programming under multiple paradigms (procedural, functional, object-oriented, generic...). Designed as an extension of C, it retains its very good performance, which makes it one of the most widely used programming languages in applications where performance is critical.

Quarter number

SD9

Prerequisites (in terms of CS courses)

1CC1000 : Information Systems and Programming
1CC2000 : Algorithmics and Complexity

Syllabus

- Introduction on computer architecture and program execution
- Preprocessor, linker, main(), namespaces
- Variables, simple types, arrays
- Definition of functions, passing arguments, returning values
- Reading and displaying
- Control structures
- Pointers, dynamic allocation
- Aggregates, enumerations
- References
- Object concepts
- Implementation in C++
- Constructors, destructor
- Methods and class attributes
- Inheritance, polymorphism
- Operator overloading
- Input/output for user defined types
- Dynamic type identification
- Exceptions
- Genericity
- Standard library
- Smart pointers
- Threads, synchronisation
- Parallelism using libraries

Class components (lecture, labs, etc.)

- Lectures : 9h00
- Tutorial classes : 6h00
- Practical work : 9h00

Grading

The exercises, started during practical work and finished with personal work, are evaluated.

Course support, bibliography

Books
- The C++ Programming Language - Bjarne Stroustrup
- Effective Modern C++: 42 Specific Ways to Improve Your Use of C++11 and C++14 - Scott Meyers
Supports
- Lectures slides
- Exercises and solutions of small classes, exercises to be carried out during practical work

Resources

This course consists of lectures to present the concepts, and small classes and practical work allowing an operational appropriation of these concepts.

Learning outcomes covered on the course

At the end of this course, students will be able to:
- write correct and efficient programs in C ++;
- use libraries adapted to the problem to be solved.

Description of the skills acquired at the end of the course

C1.4 Design: specify, implement and validate all or part of a complex system
- Produce using C++ and test a software
C6.1 Solve a problem numerically
- Use C++ to compute the solution of a problem
C6.2 Design software
- Design software in C++
C6.3 Process Data
- Use C++ to process data

3MD1510 – Software Application Engineering

Instructors : **Virginie Galtier**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ), DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **50**
On-site hours (HPE) : **22,50**

Description

The application architecture of a system defines its software components and the exchanges between them, as well as their implementation on the hardware architecture. It naturally stands at the crossroads of development and operations missions. This course provides a typology of the main application architectures and presents the concepts of "devops", a set of practices that facilitate the automation of software delivery.
Some concepts will be implemented on an illustrative architecture, in preparation for the SD9 project.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Students are expected to review their 1rt year SIP course before taking this one. They must also be comfortable in Java (self studies are provided), and with Git and Linux.

Syllabus

Introduction to devops (software life cycle, agility, CI CD pipeline, build, versioning, tests, containers, infrastructure as code): principles and overview of some tools
Typology of application architectures and associated technologies, middleware (focus on MOM)
The last course will present a topical topic.

Class components (lecture, labs, etc.)

General concepts will be presented in class and students will be encouraged to reproduce some of the live demonstrations on their personal computers. Additional resources will be provided along with exercises with solutions or self-assessment tests. Finally, more complete scenarios will be developed during lab work sessions.

Grading

Knowledge and skills will be assessed on the basis of

- a few individual written tests taking place during the lab sessions
- the SD9 project

Course support, bibliography

See the Edunao workspace.

Resources

Teaching team : Virginie Galtier and Michel Ianotto
The lab works use free software that can be installed directly on students' personal computers. A prepackaged virtual machine is also provided. Students take advantage of the clusters of the campus for some deployments.

Learning outcomes covered on the course

At the end of this course, students will be able to choose the application architecture best suited to their project and will be able to implement a software solution based on message queuing. They will be able to quickly integrate into an application development and deployment chain and will be familiar with the use of a few tools.

Description of the skills acquired at the end of the course

C3.7 Make pragmatic and informed choices with the aim of producing tangible results.
C3.8 Conceive, design, implement and reach the stage of industrialisation, Marker 2

3MD1520 – Advanced C++ programming

Instructors : **Herve Frezza-Buet**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ), DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **50**
On-site hours (HPE) : **35,00**

Description

Knowing how to code an algorithm effectively in a given programming language requires a prior understanding of the associated calculation model and how the instructions in that language are translated into machine instructions. Too many students still approach programming in a superficial and risky way, lacking the basic knowledge necessary to write elegant and effective code.
The unique strength of the C++ language is to allow the production of compiled codes close to the optimal machine code while offering different high-level programming approaches such as strong typing, object programming, functional programming and meta-programming (automatic code generation at compilation). For this reason, C++ has become the essential language for developing optimized algorithms. Its only disadvantage is its richness, which has continued to grow in its most recent versions (C++11/14/17/20) and which makes it difficult to understand the language in its entirety without adequate training.
This course is intended for students, including beginners, who want to master the different aspects of C++ programming in order to be able to write code that combines performance and elegance. The course adopts a bottom-up approach starting from the mechanisms of elementary program execution and gradually moving towards the most advanced language functionalities.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Know how to program (loops, functions, object-oriented programming basics) in a computer language, have a basic knowledge of computer architecture (processor, memory, etc.).

Syllabus

1. Compilation chain (1h30)
2. Variables and memory: typing, stack, heap, pointers, allocation, references (lvalue, rvalue)... (1h30)
3. Object programming in C++ : classes and inheritance (1h30)
4. Advanced notions of object programming: polymorphism, multiple inheritance,... (1h30)
5. Functional programming: lambda functions, callable types, wrappers, exceptions,... (1h30)
6. The standard library (1h30)
7. System programming (1h30)
8. Templates (1h30)
9. Advanced notions on templates: specialization, SFINAE, etc. (1h30)
10. Generic versus object-oriented programming, concepts (1h30)

Class components (lecture, labs, etc.)

The objective is to transmit to students a real programming know-how, on the one hand by illustrating the concepts through relevant examples of use, and on the other hand by devoting a significant part of the hourly volume to laboratory work (> 50%).

Grading

MCQ. Programming exercises.

Course support, bibliography

- Website created by the teachers
- Effective Modern C++, Scott Meyers, 2014
- Professional C++, Marc Gredoire, 2014
- A Tour of C++, Bjarne Stroustrup, 2013

Resources

Teachers: Hervé Frezza-Buet, Frédéric Pennerath
Practical works under Linux PC / g+++
Max. 40 students
2 students per machine max.

Learning outcomes covered on the course

- Know how to write a program in C++ using different programming paradigms such as object programming, functional programming and generic programming.
- To know certain aspects of the C++ language that have a decisive influence on the performance of programs during their execution.
- Be familiar with the functionalities offered by the most recent specifications of the C++ language (C++11, C++14, C++17, C++20).
- Know how to use a C++ compilation and debugging environment

Description of the skills acquired at the end of the course

C6.3 Conceive, design, implement and authenticate complex software.
C6.4 Solve problems through mastery of computational thinking skills.

3MD1530 – Statistical Models for Machine Learning

Instructors : **Frederic Pennerath**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **50**
On-site hours (HPE) : **26,00**

Description

The courses "Statistical Models for Automatic Learning" ModStat1 and ModStat2 address the problem of automatic learning from the perspective of probabilistic models and statistical estimation.
While the courses present the most useful models and methods in this context, they are not intended to be an exhaustive catalog.
The objective is more to present within a coherent theory the theoretical concepts and tools common to all these models and methods and to show how, based on modeling assumptions specific to each type of problem addressed, these concepts are logically assembled before arriving at an operational learning method.
The challenge is not only to empower students to understand and use existing models wisely, but also to design new models (or adapt existing models) to address the particularities of new problems.
The courses will also aim to achieve a continuum from theory to practice, whether in class or in TP: the hypotheses associated with a given class of problems are first identified, followed by theoretical modeling work, which leads to the definition of a model and its estimation algorithms. These results are then implemented (in Python) and evaluated on data.
Course ModStat1 will introduce the basic tools of statistical modelling while course ModStat2 will focus on models based on hidden variables.

Quarter number

SD9

Prerequisites (in terms of CS courses)

- Basic knowledge of probability theory, statistics and machine learning
- Beginner level in Python / Numpy programming

Syllabus

Total length : 13.5h of lectures, 4.5h of tutorials, 6h of labworks and 2h of written exam

Lectures (13.5h)
- Introduction and reminders (1.5h).
- Reminders on estimators (1.5h)
- Modelling, evaluation, calibration, etc : example of Naive Bayes (1.5h)
- More on Bayesian inference (1.5h)
- Bayesian Networks (3h)
- Gaussian models for classification: QDA, LDA, etc (1.5h)
- Exponential and generalized linear models (3h)

Tutorials (4.5h)
- Bayesian inference (1.5h)
- Bayesian Networks (1.5h)
- Regression (1.5h)

Labworks (6h)
- Modelling (3h)
- Linear regression and GLM (3h)

Written exam (2h)

Class components (lecture, labs, etc.)

- The courses use demos or examples to illustrate abstract concepts.
- Tutorials (1.5h) and labworks on computers (3h) give the opportunity to apply notions seen during lectures from both theoretical and practical perspectives.

Grading

Written exam of 2 hours without handouts on course questions and exercises.

Course support, bibliography

- Course material (Course presentation, handout)
- "Machine Learning – A Probabilistic Perspective", Kevin Murphy (MIT Press, 2012)
- "Bayesian Reasoning and Machine Learning", David Barber (Cambridge University Press, 2012)
- "All of Statistics: A Concise Course in Statistical Inference", Larry Wasserman (Springer-Verlag, 2004)

Resources

- Teachers: Frédéric Pennerath (lectures, exercise sessions, labworks), Joël Legrand (labworks)
- Programming with Python and its standard libraries.
- 1 group fur exercise sessions
- 2 groups for labworks
- 2 students max per PC

Learning outcomes covered on the course

- Be able to choose a statistical model/method adapted to the problem under consideration and implement it appropriately
- Be able to understand the theoretical concepts underlying a statistical inference method presented in a scientific article.
- Be able to implement a model / statistical method in a language such as Python.
- Be able to adapt a model/method to take into account the specificities of the problem being addressed.

Description of the skills acquired at the end of the course

C1.2 - Use and develop appropriate models, choose the right modeling scale and relevant simplifying assumptions to address the problem
C2.1 - Have studied in depth a field or discipline related to the basic or engineering sciences
C6.4 - Solving problems in a computational thinking process

3MD1540 – Machine learning

Instructors : **Herve Frezza-Buet**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **50**
On-site hours (HPE) : **37,00**

Description

The course introduces machine learning through a global presentation of the field, before dealing more precisely with theoretical aspects of statistical learning and several algorithms. The practical work presents situations where the implementation of methods requires an understanding of the theory associated with them.

Quarter number

SD9

Prerequisites (in terms of CS courses)

This course requires knowledge of linear algebra and probability theory. For practical works, a good knowledge of python (especially numpy) is required.

Syllabus

The course presents a broad view of the field of machine learning, then goes into more detail on the concepts of risk, preanalysis and data preparation, support vector machines, decision trees, boosting and bagging, vector quantization.

Class components (lecture, labs, etc.)

The teaching consists of lectures that describe in depth the theoretical concepts related to algorithms while presenting demonstrations illustrating the implementation of these concepts. The practical work aims to implement the methods, while keeping in mind the importance of understanding the role of the parameters and the methods' limitations. The exam is also prepared by addressing annals in tutorial classes.

Grading

The module will be evaluated by a written exam, where the idea is to test the student's ability to use methods in a clever way, to analyze the results of an algorithm, etc.

Course support, bibliography

The course is accompanied by a written support in English, in which the bibliographical references of the field are cited.

Resources

The courses and practical work are given by Hervé Frezza-Buet and Jérémy Fix. The courses present theoretical aspects, mathematical proofs, but are also illustrated by demonstrations of algorithms. The practical work will be done in Python, using sickit-learn, in pairs.

Learning outcomes covered on the course

- Understand the theoretical foundations of the machine learning methods presented.
- Implement these methods appropriately, without considering them as black boxes.
- Make the link between the different methods.

Description of the skills acquired at the end of the course

C3.5, Marker 1: Put forward new tools with either continual progress or disruptive solutions as the goal
C3.6, Marker 1: Evaluate the efficiency, feasibility and strength of the solutions offered. / proposed solutions.
C3.7, Marker 2: Make pragmatic and informed choices with the aim of producing tangible results.

3MD2010 – Hyperbolic systems of conservation laws

Instructors : **Pauline Lafitte, Cedric Enaux**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Present in many diverse and varied physical models (fluid flow, road traffic, pandemic dynamics, etc.), conservation laws are partial differential equations with a simple form, but whose non-linear nature alone justifies the emergence of a modern branch of applied mathematics. Indeed, when they are non-linear, conservation laws develop discontinuous solutions (formation and propagation of "shocks") independently of the regularity of the initial data.
The presence of discontinuities explains the failure of numerical methods of the Finite Difference type - based on the hypothesis of regular solutions - to converge towards the solution of interest. Moreover, the absence of a weak formulation verifying the hypotheses of the Lax-Milgram theorem prevents the use of Finite Elements type methods. Thus the numerical resolution of the conservation laws requires the use of specific numerical methods, called Finite Volumes, whose construction and efficiency can only be explained by the mathematical and numerical analysis of the equations considered.

Quarter number

SG10

Prerequisites (in terms of CS courses)

First-year PDE course

Syllabus

- sessions 1 and 2 (2x3h): mathematical theory of hyperbolic systems of conservation laws (hyperbolicity, classical solutions, characteristics method, weak solutions, Rankine-Hugoniot relations, etc.).
- session 3 (3h): individual project - start up (presentation of the subjects, mathematical analysis, handling of the computer tool)
- sessions 4 and 5 (2x3h): numerical methods for hyperbolic systems of conservation laws (reminders of Finite Differences, Finite Volumes method, construction and analysis of some digital streams, etc.).
- session 6 (3h): individual project - continuation (numerical analysis and development of a Finite Volume schema for problem solving)

Class components (lecture, labs, etc.)

Organization of the course: 4x3h of lectures + 2x3h of individual project follow-up.

Grading

Written exam (3h) and individual project presentation (15min)

Course support, bibliography

[1] E. Godlewski & P.-A. Raviart (1995), Numerical approximation of hyperbolic systems of conservation laws, Springer ISBN 0-387-94529-6.
[2] R.J. LeVeque (1992), Numerical methods for conservation laws, Birkhäuser ISBN 3-7643-2723-5.
[3] D. Serre (1999), Systems of conservation laws 1: hyperbolicity, entropies, shock waves, Cambridge University Press ISBN 0-5215-8233-4.

Resources

Teaching team: Cédric Enaux

Learning outcomes covered on the course

Fundamentals and tools for the mathematical and numerical analysis of conservation law systems

Description of the skills acquired at the end of the course

To acquire know-how, through the followed realization of an individual project of digital resolution of a given system.

3MD2020 – Hamilton-Jacobi equations

Instructors : **Pauline Lafitte**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**
Elective category :
Advanced level :

Description

The objective of this course is to present an overview of different approaches to characterize and numerically approach the equations describing the propagation of fronts, and more generally the Hamilton-Jacobi equations. These equations intervene in several domains such as wave propagation (in high frequency approximation), interface propagation modeling or the calculation of shorter (geodetic) paths in optimal control theory.

After studying three approaches to the Hamilton-Jacobi equation (characteristics, Euler-Lagrange equations and variational calculus) and introducing the notion of viscosity solution, the link between the Hamilton-Jacobi equation and optimal control will be sketched. Finally, different numerical methods will be presented, analyzed (stability, convergence) and programmed on computer.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Notions in analysis and discretization, PDEs

Syllabus

1) Introduction
2) Three approaches
    - Resolution by the characteristics method
    - Euler-Lagrange equations
    - Variational calculus and ODE
2) Viscosity solutions
3) Optimal control
4) Finite difference diagrams
5) Interface propagation schemes
    - Level-Sets
    - Fast-Marching

Class components (lecture, labs, etc.)

Lectures at the blackboard.

Grading

Written exam.

Course support, bibliography

[1] L. C. Evans. Partial differential equations, volume 19 of Graduate Studies in Mathema- tics. American Mathematical Society, Providence, RI, 1998.
[2] R. P. Fedkiw and S. Osher. Level set methods : An overview and some recent results. J. Comput. Phys, pages 463–502, 2001.
[3] Pierre-Louis Lions. Generalized solutions of Hamilton-Jacobi equations, volume 69 of Research Notes in Mathematics. Pitman (Advanced Publishing Program), Boston, Mass., 1982.
[4] E. Trélat. Contrôle optimal. Mathématiques Concrètes. [Concrete Mathematics]. Vuibert, Paris, 2005. Théorie & applications. [Theory and applications].
Various recent research articles that will be given as they become available.

Resources

Teaching team: Pauline Lafitte (CentraleSupélec)

Learning outcomes covered on the course

Detailed knowledge of the behaviour of the solutions of the HJB equations, the modelling of propagation fronts and their approximations.

Description of the skills acquired at the end of the course

Both theoretical and numerical expertise for the solution of certain non-linear problems by proposing to program, test and compare these methods on concrete problems.

3MD2030 – Optimisation and calculus of variations

Instructors : **John Cagnol**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Optimization is the selection of a "best" element from a set of possibilities. There are many applications in engineering, finance, economics, IT, etc. Optimizing therefore involves defining a criterion for "best", characterizing the set of possibilities and implementing methods to search for this best element in the admissible set.
It is possible to use methods based on existing and available data (data science), it is also possible to use methods related to the calculation of variations or formal methods. Each problem class, each context, must be analyzed to determine the most relevant and effective method.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Analysis, PDEs / CIP (1A), Modeling (1A), Algorithms and Complexity (1A), SIP (1A), Control (2A), Optimization (2A), Engineering challenges of 1A and 2A, MDS 3rd Year Core Curriculum Optimization Course.

Syllabus

After having introduced the general principles of variation calculation and optimization, some of which extend the elements given in the core course, we will present the methods for modeling these problems, i.e. the formalization of the optimization problem for a real or virtual phenomenon of interest. Among the methods presented, we will discuss the principle of least action. We will study the different optimization methods for these methods. The common core course takes as a framework the case where the set of admissible states is a closed subset of a Banach space; in this course we will also be interested in some cases that do not fall within this framework, in particular the question of shape optimization where the variable to be optimized is the geometry of the domain.

Class components (lecture, labs, etc.)

Lectures.

Grading

A midterm test. [25% of the overall grade]
A mini-project [25% of overall grade]
A final exam [50% of overall grade]

Course support, bibliography

Clarke Frank H (1983) Optimization and nonsmooth analysis. Chischester Brisbane: Wiley-Interscience, New York
Cournède Paul-Henry Optimisation continue et contrôle optimal : cours de 3e année de l’École centrale Paris. Ecole Centrale Paris (CentraleSupélec)
Delfour Michel C. (2012) Introduction à l’optimisation et au calcul semi-différentiel. Dunod, Paris
Pierre Donald A (1969) Optimization theory with applications. J. Wiley & Sons, New York
Sokolowski J, Zolesio JP (1992) Introduction to shape optimization : shape sensitivity analysis. Springer-Verlag

Resources

Teaching team : John Cagnol

Learning outcomes covered on the course

Methods for formalizing the optimization problem for a real or virtual phenomenon of interest

Description of the skills acquired at the end of the course

Within the framework of a mini-project, students will be led to take a real problem, model it, formalize the optimization problem, determine the optimal method and then implement it.

3MD2040 – Moment methods for a kinetic equation

Instructors : **Frederique LAURENT-NÈGRE, Pauline Lafitte**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Moment methods are used in various engineering applications: description of gas dynamics, particle populations (drops, soot, nanoparticles), radiative transfers,... In this course, it is a matter of understanding how these macroscopic methods are developed from a so-called mesoscopic description of the kinetic type, and in particular which types of closures are used, how to characterize the space in which these moments (space of moments), how to study certain mathematical properties of the models obtained and how to give some methods for solving the equations, in link with their mathematical properties and preserving the space of moments.

Prerequisites (in terms of CS courses)

Basics of algebra and measurement theory

Syllabus

1. Introduction: applications - kinetic equation / population balance equation
2. Moment space - link with the orthogonal polynomial theory
3. Classical methods of moments for mono-atomic gases - mathematical properties
4. Case of particle populations: closures in the mono-varied case
5. Numerical methods feasible in the single-variable case
6. Multi-variate cases: additional theoretical and numerical difficulties - some examples of models and numerical methods
7. Case of radiative transfer: moments on the unit sphere

Class components (lecture, labs, etc.)

Lectures.

Grading

Oral exam (article summary) and homeworks.

Course support, bibliography

[1] D. L. Marchisio, R. O. Fox, Computational Models for Polydisperse Particulate and Multiphase Systems, Cambridge University Press, Cambridge, UK, 2013.
[2] H. Dette, W. J. Studden, The Theory of Canonical Moments with Applications in Statistics, Probability, and Analysis, Wiley-Interscience, 1997.

[3] J. B. Lasserre, Moments, positive polynomials and their applications, Vol. 1 of Imperial College Press Optimization Series, Imperial College Press, London (2010).

Resources

Teaching team: Frédérique Laurent-Nègre (CNRS, laboratoire EM2C), Teddy Pichard (Ecole Polytechnique)

Learning outcomes covered on the course

The aim here is to understand in which space moments evolve, how we close the equations on moments, both in the mono-varied case (moment with respect to a single variable) and in the multi-varied case, which is very different from a theoretical point of view. We will also see some methods of numerical resolution of these equations, preserving the space of moments.

Description of the skills acquired at the end of the course

Fine understanding of the methods of obtaining macroscopic equations for an underlying kinetic equation. Understanding of the issues involved in the numerical resolution of these models.

3MD2050 – Mathematical analysis of Physics problems with irregular and fractal boundaries

Instructors : **Anna Rozanova-Pierrat**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

In today's world, we need to face up to problems that contain complex, highly irregular geometries, one of which the simplest modeling brings out edges or geometries pre-fractal or fractal (cracks in the materials, the ribs of the Kingdom
United, electrodes, lungs, cancerous tumors, noise walls acoustics, ...). This axis of surface modeling (in 3D) or of the
infinite (2D) lengths of domains with finite volume and measurements of fractional dimension of the edges by fractals has developed a lot recently since the publication of B. Mandelbrot's book "The fractal geometry of nature" in 1982.

Depending on the application and the nature of the phenomenon studied (we could cite two typical examples: heat propagation if cooling is the goal, for microprocessors for example, or the propagation of waves for the most efficient wave absorption problem), the mathematical model (in the first case the heat equation and in the second case the equation wave or Helmholtz in frequency) is different but it inherits the properties known for the Poisson equation, or even just the properties of the Laplacian, in domains with fractal boundaries.
The course thus proposes the detailed study of elliptic problems on domains with fractal edges which are generalized into a notion of d-sets (thus sets of dimension d which is a real number). The results presented in this course have developed from the 80's of the last century and are the basis for many open questions in mathematics, that are increasingly being developed to meet the demand of physical, medical and engineering applications.

Quarter number

SG10

Prerequisites (in terms of CS courses)

The first-year PDE course

Syllabus

The Sobolev spaces and their properties are studied in detail.

We treat the Poisson equation on non-convex domains (with a corner entering a ball for example) and we study the regularity of the weak solution.

The notion of d-set and d-measurement is then presented by giving typical examples of fractal edges, such as Von Koch's fractals.

Aspects of functional analysis are defined to find the solution of
Poisson's equation on a fractal edge domain :
1) the existence of a continuous extension operator that allows the functions to be extended without loss of their regularity, i.e. belonging to a Sobolev space
2) the introduction of the trace operator for regular distributions, the study of its compactness

3) the Green's formula and the integration by parts on domains with
edges given by d-sets

We will then study the Poisson problem for different cases of conditions at the edge and we will look at the contribution of irregular geometry to the spectral problem associated with Laplacian. We will establish for a bounded domain with a fractal edge the existence of a sequence of eigenvalues and an orthonormal eigenmode base. The phenomenon of eigenmode localization will be studied. We apply the Galerkin method to show the well-posed character of the heat equation on the same type of irregular domains. We will study the convergence of the domains and the corresponding solutions (Mosco convergence).

Class components (lecture, labs, etc.)

Lectures, 4 1hr labs.

Grading

A 3-hour written exam.

Course support, bibliography

[1] B. Mandelbrot. The fractal geometry of nature, Cover of the hardcover edition, 1982.
[2] L. C. Evans. Partial Differential Equations. Graduate Studies in Mathematics, 1994.
[3] K.J. Falconer. Techniques in Fractal Geometry. Chichester: John Wiley, 1997.
[4] Barlow, M.T., Kigami, J.: Localized eigenfunctions of the Laplacian on p.c.f. self-similar sets. J. London. Math. Soc.(2) 56, 320–332 (1997)
[5] A. Jonsson and H. Wallin, Boundary value problems and brownian motion on fractals, Chaos, Solitons & Fractals, 8 (1997), 191–205.
[6] K. Arfi, A. Rozanova-Pierrat, Dirichlet-to-Neumann or Poincaré-Steklov operator on fractals described by d-sets. DCDS - S, 12 (2019), 1-26
[7] M. Filoche, S. Mayboroda. Universal mechanism for Anderson and weak localization. PNAS, 109 (2012), 14761–14766.

Resources

Teaching team: Anna Rozanova-Pierrat (CentraleSupélec)

Learning outcomes covered on the course

Irregular and regular boundaries: impact on PDE's solutions; Sobolev extension domains; trace operator on a multi-fractal boundary, Green formulas on the irregular boundaries; compacts and compact operators; weak and weak* convergence; Sobolev spaces; spectral problems and Galerkin method; localization of eigenfunctions of the Laplacian; convergence of domains (in the sens of Hausdorff and of caracteristic functions); Mosco convergence and gamma-convergence (approximation of solutions on domains with fractal boundaries by the solutions on more regular domains).

Description of the skills acquired at the end of the course

This theoretical course in the themes of PDEs, functional analysis and modeling aims to be of interest to those who wish to do research in the field of applied mathematics, as well as in the context of R&D, given the application to engineering problems that the theory of this course will help to solve.

3MD2210 – Limit Theorems

Instructors : **Alexandre Richard**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

In science and physics particularly (but also in biology, complex systems, etc.), we are looking for equations (ODE, EDP(S), etc.) describing macroscopic phenomena from observed properties such as the laws of conservation or wave propagation.
However, these macroscopic equations often represent an approximation of the large scales of microscopic systems composed of large numbers of particles interacting according to elementary physical principles, for example atoms/molecules in physics; neurons/ion channels in neuroscience economic agents, etc. To deduce from these microscopic systems the laws of macroscopic is often as fundamental a problem as it is difficult.
The objective of this course will be to present some mathematical tools ofconvergence of random variables, and to apply them to systems of Interacting probabilistic particles whose number of components tends towards infinity. At the limit, we will identify according to the examples the equations of the fluid mechanics or biology.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Discrete-time Markov chains and martingales; Stochastic calculus.

Syllabus

I Introduction and "reminders" on Markov processes
II Limit Theorems
- Tension of measures in metric spaces
- Convergence in distribution and Prokhorov's Theorem
- Tightness in the space of continuous functions and Donsker's Theorem

III Stroock-Varadhan theory of diffusion approximation
IV Interacting particle systems and propagation of chaos
- Mean field limit of particle systems with regular coefficients
- Martingale problem, McKean-Vlasov's EDS and the propagation of chaos

Class components (lecture, labs, etc.)

Lectures, with exercises in class or at home.

Grading

One homework and a 3 hours written exam.

Course support, bibliography

* P. Billingsley, Convergence of Probability Measures, Wiley, 1999.
* A.-S. Sznitman, Topics in propagation of chaos, St-Flour Lecture Notes, 1988.
* Various recent research articles whose references will be provided as they become available.

Resources

Teaching team: Alexandre Richard (CentraleSupélec)

Learning outcomes covered on the course

The classical limit theorems, and in particular Donsker's theorem ;
Particle approximation and probabilistic representation of PDEs;
Martingale problems and chaos propagation.

Description of the skills acquired at the end of the course

Mastering the convergence of random variables in certain functional spaces by tightness methods ;
Students will master the concepts of approximation and scaling limits.

3MD2220 – Quantification of uncertainties in numerical simulations

Instructors : **Claire CANNAMELA, Pauline Lafitte**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Numerical simulation has become an essential tool in research and development by creating a bridge between theory and experience. Simulation is based on calculation codes capable of describing and predicting complex physical systems. These codes are composed of input parameters representing the state of the system and output responses characterizing it. The input parameters can be subject to multiple sources of uncertainty (measurement errors, natural variability, lack of information) and the outputs are then subject to uncertainties that need to be characterized. Uncertainty analyses can be varied: estimating a mean value and variability, guaranteeing the proper functioning of a system, searching for the main sources of variability, etc.

Prerequisites (in terms of CS courses)

Statistics (1st and 3rd year)

Syllabus

- Introduction to the "uncertainty approach" (principle, steps, etc.)
- Random variable modeling and dependency
- Monte Carlo methods for the propagation of uncertainties
- Rare events (low probability estimate)
- Around linear regression (optimal model and design of experiments)
- Gaussian regression and design of exploratory experiments
- Sensitivity analysis (prioritization of sources of uncertainty)
- Introduction to robust optimization

Class components (lecture, labs, etc.)

Each session is composed of a lecture part and a practical work part. The labss are conducted in R, however no knowledge of this language is necessary. Scripts are provided and the emphasis is on the analysis and interpretation of the results.

Grading

The evaluation takes place in the form of a project.

Course support, bibliography

[1] E. de Rocquigny , N. Devictor, Stefano Tarantola, editors. Uncertainty in Industrial Practice. Wiley, 2008.
[2] R.Ghanem, D. Higdon, H. Owhadi, editors. Handbook of Uncertainty Quantificatio. Springer, 2017.
Handbook of Uncertainty Quantification

Resources

Teaching team: Claire Cannamela, Engineer-researcher at CEA

Learning outcomes covered on the course

The objectives of this course are, on the one hand, to identify the different steps of the "uncertainty approach" and, on the other hand, to understand the main methods essential to the resolution of uncertainty analyses.

Description of the skills acquired at the end of the course

The first goal is to make students aware of the importance of taking uncertainties into account in numerical simulations. The second objective is to know how to implement the "uncertainty methodology" on simple examples.

3MD2240 – Stochastic filtering and control

Instructors : **Nina-Hadis Amini**
Department : **MATHÉMATIQUES, MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

In this course, we will introduce stochastic filtering and stochastic control. We consider dynamical systems which are described by stochastic differential equations driven by Wiener processes. In filtering theory, the aim is to provide estimation of the state of a dynamical system based on partial observation processes. The observation processes are also described by stochastic differential equations. This problem arrives in many fields such as telecommunication, mathematical finance, etc. Here, we give an introduction to different methods to solve such a problem.In the second part of this course, we introduce stochastic control theory and we define stochastic stabilization. Finally, we mention some applications of the developed methods in different fields.

Prerequisites (in terms of CS courses)

Stochastic processes and stochastic calculus

Syllabus

- Kalman filtering in discrete and continuous-time;
- Non-linear stochastic filtering: the change of reference measure method; Kallianpour-Striebel formula; the Zakai equation and the Kushner-Stratonovich equation;
- Introduction to stochastic control and stochastic stabilization;
- Applications in different fields.

Class components (lecture, labs, etc.)

Lectures, notes and slides.

Grading

Project with defense.

Course support, bibliography

- Karatzas, I.- Shreve, S. Brownian motion and stochastic calculus, Springer, Berlin, 1991.
- Oksendal, B. Stochastic Differential Equations. An Introduction with Applications, Springer, Berlin, 2013.
- A. Bain and D. Crisan. Fundamentals of Stochastic Filtering. New York: Springer, 2009.
- H. Kushner. Stochastic stability and control. Academic Press, 1967.

Resources

Teaching team: Nina Amini (CNRS)

Learning outcomes covered on the course

Basics of filtering theory and stochastic control.

Description of the skills acquired at the end of the course

Application and manipulation of stochastic control.

3MD3010 – Foundations of Distributed and Large Scale Computing Optimization

Instructors : **Emilie Chouzenoux, Fragkiskos Malliaros**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

In a wide range of application fields (inverse problems, machine learning, computer vision, data analysis, networking,...), large scale optimization problems need to be solved.
The objective of this course is to introduce the theoretical background which makes it possible to develop efficient algorithms to successfully address these problems by taking advantage of modern multicore or distributed computing architectures. This course will be mainly focused on nonlinear optimization tools for dealing with convex problems. Proximal tools, splitting techniques and Majorization-Minimization strategies which are now very popular for processing massive datasets will be presented. Illustrations of these methods on various applicative examples will be provided.

Quarter number

SG10

Prerequisites (in terms of CS courses)

No official prerequisite.

Syllabus

The course consists of eight sessions (3h each) combining lectures and exercises. The following concepts will be presented:
1. Background on convex analysis
2. Parallel and distributed proximal splitting methods
3. Parallelization through Majorization-Minimization approaches

More information cab be found on the course website:
https://pages.saclay.inria.fr/emilie.chouzenoux/ECP/index.htm

Class components (lecture, labs, etc.)

Le cours sera basé sur les éléments suivants :
Cours magistraux
Sessions de laboratoire
Travaux à domicile/projets

Grading

- Report: code + answer to questions (jupyter notebook using Python 3), 1 report for 2 students.
- Each report is due no later than two weeks after the corresponding lab session.
- Written exam

Course support, bibliography

More information can be found on the website of the course:
https://pages.saclay.inria.fr/emilie.chouzenoux/ECP/index.htm

Description of the skills acquired at the end of the course

By the end of the course, the student will acquire knowledge and skills on distributed and parallel optimization techniques.

3MD3015 – Large Scale Modeling

Instructors : **Sarah Lemler, Fragkiskos Malliaros**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

In this course, we will look at the issue of high dimensionality when the number of covariates (or explanatory variables) exceeds the number of observations.
We will show the limitations of standard procedures in this context. We present variable selection methods, highlighting their advantages and disadvantages from both a theoretical and a practical point of view. We will present regularization methods adapted to different problems. Finally, we will introduce screening methods to handle the case of ultra-high dimensions when regularization methods are insufficient. There will be practical exercises in R to put into practice the various concepts covered in the course.

Prerequisites (in terms of CS courses)

Good knowledge of statistics

Syllabus

- Motivations
- Variable selection (Cp-Mallows, AIC, BIC…)
- Regularization methods (Ridge regression, Lasso and Lasso variants for linear and logistic regressions)
- Screening methods (in the case of ultra-high dimension)

Class components (lecture, labs, etc.)

Lectures, practical exercises in R, exam

Grading

Project, written exam

3MD3020 – Deep Learning

Instructors : **Fragkiskos Malliaros, Maria Vakalopoulou**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

With the increase of computational power and amounts of available data, but also with the development of novel training algorithms and new whole approaches, many breakthroughs occurred over the few last years in Deep Learning for object and spoken language recognition, text generation, and robotics. This class will cover the fundamental aspects and the recent developments in deep learning in different domains: Computer Vision, Natural Language Processing, and Deep Reinforcement Learning.

Quarter number

SG10

Prerequisites (in terms of CS courses)

There is no official prerequisite for this course. However, the students are expected to have basic knowledge of Python.

Syllabus

- history of deep learning and its relation to cognitive science;
- feedforward networks, regularisation and optimization;
- representation learning & siamese networks;
- GAN & transfer learning;
- recurrent networks and LSTM for Natural Language Processing;
- object detection;
- self-supervised methods;
- deep reinforcement learning.

Class components (lecture, labs, etc.)

Each section of the course is divided into 1h30' lecture and 1h30' lab. The labs will allow the students to start developing the mini-projects on which the evaluation is based, and receive feedback.

Grading

The evaluation of the course will be based on 2 individual mini-projects on object recognition, natural language processing, and reinforcement learning.

Course support, bibliography

Reading material
- Deep Learning. Ian Goodfellow, Yoshua Bengio, and Aaron Courville, MIT Press, 2016.

Resources

- Software tools: Python, Keras, PyTorch
- Related conferences: NIPS, ICML, ICLR, CVPR, ECCV, ICCV
- Related Courses: Deep Learning in Practice (second semester)

Learning outcomes covered on the course

The course aims to introduce students to Deep Learning through the development of practical projects. We expect that by the end of the course, the students will be able to implement and develop new methods in different domains.

3MD3021 – Theoretical principles for Deep Learning

Instructors : **Fragkiskos Malliaros, Hédi Hadiji, Sarah Lemler**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Machine learning algorithms involving deep neural networks have accumulated empirical successes at a spectacular rate over the recent years. Many of those accomplishments cannot be explained by conventional wisdom coming from standard learning theory. Moreover, as the popularity of deep learning grows, the gap between theory and practice keeps widening. Building the groundworks for a satisfying theory of deep learning, with the ultimate goal of providing valuable insights to practitioners, is a major challenge in modern research.

In this class we will discuss recent theoretical progress made towards describing the empirical performance of deep methods. Our main focus will be the study of the surprisingly good *generalization* ability of deep networks. Consider a classification task, in which, given a training set of features and labels, we wish to predict the unknown label of a new test feature. From a superficial glance at classical learning theory, one would expect very large and complex models to overfit on training data, yet practice has proved again and again that neural nets perform well despite massive overparameterization. We will describe some ideas that have been proposed to explain this phenomenon; subjects we may discuss are: theories of generalization (capacity, margin, stability, compression, …), implicit regularization by SGD and the loss landscape, PAC bayes bounds, theoretical approximation of large nets (neural tangent kernel).

Prerequisites (in terms of CS courses)

- elementary probability theory, statistics, linear algebra
- optimization: convexity, gradient descent
- learning theory: PAC-learning, VC dimension (a crash course will be included but students who have never seen this will need extra work to catch up)
- basics of deep learning

Syllabus

- Crash course on statistical learning theory and optmization
- PAC bounds for neural networks
- PAC-bayes and compression bounds
- Inductive biases introduced by optimisation
- NTK and learning dynamics

Class components (lecture, labs, etc.)

Lectures and practical sessions

Grading

Presentation of a research article in a given list. Presentation will include:
- a discussion of the global context and the main findings in the paper,
- a proof sketch of the theoretical results

- some numerical illustration.

Resources

Teacher: Hédi HADIJI

Learning outcomes covered on the course

- an in-depth understanding of the specific aspects of deep learning that differentiate it from other machine learning techniques
- knowledge of different theoretical evaluation criteria for machine learning methods
- knowledge of the main hypotheses put forward by the scientific community to explain the successes of deep learning, as well as the limits of these hypotheses.

Description of the skills acquired at the end of the course

The main skills developed during this course will be

> C1.1 - `Analyze the global behavior of a complex system' The central theme of the course is the general analysis of the behavior of methods containing neural networks.
> C1.3 - `Estimate parameter values and evaluate approximation quality'. Students will learn to anticipate the impact of various parameters guiding the training, and a fortiori the performance, of deep neural networks.
> C1.4 - 'Prototyping, realizing and validating complex systems': the theoretical knowledge acquired will enable students to develop an intuition that will guide them in the development of deep learning methods. These insights will be illustrated by practical exercises

The course content will be based on research results, and students will be encouraged to read recent research articles. TD/TP sessions and the final presentation will enable students to "Integrate and consolidate newly acquired skills within a body of knowledge (C2.2)".

As the subject of the course is deep learning, practical sessions will be offered to illustrate some of the ideas discussed in class. Students will be asked to 'Numerically solve a problem (C.6.1)' and 'Design software (C6.2)'. They will also look at the nature of training data, and its impact on the trained model - 'C6.3 - Processing data'.

3MD3030 – Geometric Methods in Data Analysis

Instructors : **Fragkiskos Malliaros**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Data analysis is the process of cleaning, transforming, modeling or comparing data, in order to infer useful information and gain insights into complex phenomena. From a geometric perspective, when an instance (a physical phenomenon, an individual, etc.) is given as a fixed-sized collection of real-valued observations, it is naturally identified with a geometric point having these observations as coordinates. Any collection of such instances is then seen as a point cloud sampled in some metric or normed space.
This course reviews fundamental constructions related to the manipulation of such point clouds, mixing ideas from computational geometry and topology, statistics, and machine learning. The emphasis is on methods that not only come with theoretical guarantees, but also work well in practice. In particular, software references and example datasets will be provided to illustrate the constructions.

Quarter number

SG10

Prerequisites (in terms of CS courses)

- There is no official prerequisite for this course. However, the students are expected to have a good familiarity with:
- Basics in algorithms (notions of complexity)
- Basics in linear algebra, geometry, probability theory.

Proficiency with one programming language (C/C++, python, R) is also expected.

Syllabus

Nearest neighbors in Euclidean and metric spaces: search data structures and algorithms

- Nearest neighbors in Euclidean and metric spaces: analysis
- Dimensionality reduction algorithms
- Covers and nerves: geometric inference and the Mapper algorithm
- Clustering algorithms and introduction to persistent homology
- Statistical hypothesis testing and two-sample tests (TST)
- Comparing high-dimensional distributions, comparing clustering
- Shape signatures: stability and statistical aspects

Class components (lecture, labs, etc.)

Each course involves two lectures (1h30' each), providing the theoretical foundations, together with illustrations of the methods on practical datasets.

Grading

The evaluation of the course will be based on a project, undertaken by groups of two students. Two types of projects will be provided, to match the background of students. On the one hand, projects with a mathematical-algorithmic inclination will provide the opportunity to deepen the theoretical understanding of a recent research result. On the other hand, data processing projects will provide the opportunity to gain a fine understanding on complex data, using (selected) methods studied during the class.
For each project, the code developed and a report will be returned.

Course support, bibliography

A reading list for each course is provided on the course web site:
https://www-sop.inria.fr/abs/teaching/centrale-FGMDA/centrale-FGMDA--cazals-carriere.html#

Learning outcomes covered on the course

- The goals are twofold:
- to master the fundamentals of geometric data analysis,
- to acquire expertise to decide which methods are practically best suited to deal with data of a certain type

Description of the skills acquired at the end of the course

The students are expected to master the fundamentals of geometric data analysis, and to acquire expertise to decide which methods are practically best suited to deal with data of a certain type.

3MD3040 – Graphical Models: Discrete Inference and Learning

Instructors : **Fragkiskos Malliaros**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Graphical models (or probabilistic graphical models) provide a powerful paradigm to jointly exploit probability theory and graph theory for solving complex real-world problems. They form an indispensable component in several research areas, such as statistics, machine learning, computer vision, where a graph expresses the conditional (probabilistic) dependence among random variables.

This course will focus on discrete models, that is, cases where the random variables of the graphical models are discrete. After an introduction to the basics of graphical models, the course will then focus on problems in representation, inference, and learning of graphical models. We will cover classical as well as state of the art algorithms used for these problems. Several applications in machine learning and computer vision will be studied as part of the course.

Quarter number

SG10

Prerequisites (in terms of CS courses)

- Solid understanding of mathematical models
- Linear algebra
- Integral transforms
- Differential equations
- Ideally, a basic course in discrete optimization

Syllabus

- Introduction to the course
- Graphical Models
- Belief Propagation
- Introduction to Graph Cuts
- Graph cuts + Primal-dual, Part I
- Graph cuts + Primal-dual, Part II
- Recommender systems + 2 papers
- Causality
- Learning
- Bayesian Networks
- Project presentations

Class components (lecture, labs, etc.)

Lectures and project

Grading

- Projects in groups of at most 3 people
- Report and presentation
- Topics: your own or given in the class

Course support, bibliography

Probabilistic graphical models: principles and techniques, Daphne Koller and Nir Friedman, MIT Press
Convex Optimization, Stephen Boyd and Lieven Vanderbeghe
Numerical Optimization, Jorge Nocedal and Stephen J. Wright
Introduction to Operations Research, Frederick S. Hillier and Gerald J. Lieberman
An Analysis of Convex Relaxations for MAP Estimation of Discrete MRFs, M. Pawan Kumar, Vladimir Kolmogorov and Phil Torr
Convergent Tree-reweighted Message Passing for Energy Minimization, Vladimir Kolmogorov

Resources

The course will be based on two modules:

- Lectures
- Project for the evaluation

Description of the skills acquired at the end of the course

The students will acquire knowledge with respect to:

- Fundamental methods
- Real-world applications
- Also, pointers to using these methods in your work

3MD3050 – Introduction to Visual Computing

Instructors : **Fragkiskos Malliaros, Maria Vakalopoulou**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Computer vision is an interdisciplinary field with the goal of enabling automatical processing and understanding of digital images. These images can be captured by video cameras, radars, satellites or even very specialised sensors such as the ones used for medical purposes. This course covers both theoretical and practical aspects of computer vision. It has been designed to provide an introduction to computer vision, including fundamentals on image processing, computational photography, multiview geometry, stereo, tracking, segmentation and object detection. It will expose students to a number of real-world applications that are important to our daily life. The course will be focusing only on classical computer vision techniques, presenting a detailed overview of classical vision methods, while it does not cover deep learning-based methods.

Quarter number

SG10

Prerequisites (in terms of CS courses)

There is no official prerequisite for this course. However, the students are expected to have a background in linear algebra, real multivariable analysis, basic probabilistic theory, statistics and computer programming in Python.

Syllabus

- Introduction to Computer Vision
- Low vision
- Feature Selection/ Matching
- Stereo Vision/ Optical Flow
- Image Segmentation
- Image Recognition
- Video Processing
- Advanced Vision Topics

Class components (lecture, labs, etc.)

- 8 x 3h. Depending on the lecture either 3h lecture or 1h30 lecture/ 1h30 TP
- For the practical sessions (TPs) students should bring their personal laptops

Grading

The evaluation of the course will be based on the following:
- Assignments: the assignments will include theoretical questions as well as hands-on practical tasks and will familiarize the students with basic algorithms and applications in computer vision.
- Project: The students are expected to form groups of 2-3 people, propose a topic for their project, and submit a final project report.

Learning outcomes covered on the course

The course aims to introduce students to computer vision by both theoretical and practical sessions.
We expect that by the end of the course, the students will:

- be familiar with theoretical and practical aspects of classical computer vision,
- understand the principles and have an overview of classical vision algorithms,
- have been exposed to a wide range of classic and modern fundamentals of computer vision,
- develop the practical skills necessary to build computer vision applications.

3MD3055 – Computer vision

Instructors : **Antonio SILVETI-FALLS, Sarah Lemler, Fragkiskos Malliaros**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Optimization is the workhorse of modern computer vision and responsible for much of its success, with first-order optimization offering a scalable way to solve many of the practical problems that arise in the field. This course explores the theoretical foundations and practical aspects of applying first-order optimization techniques to computer vision problems. The course covers some foundational concepts in convex analysis and optimization, wavelets, sparse feature learning, image processing, deep learning, and epipolar geometry. There will be practical sessions for implementing these techniques to solve real-world problems from image denoising, deblurring, inpainting, super resolution, and stereo matching.

Prerequisites (in terms of CS courses)

A first course in convex optimization or convex analysis, real analysis (e.g., the content of the CIP course without the probability parts), familiarity with python programming and numpy; an introductory course in deep learning or computer vision would also be useful.

Syllabus

Some foundational concepts in convex analysis and optimization, wavelets, sparse feature learning, image processing, deep learning, and epipolar geometry (time permitting).

Class components (lecture, labs, etc.)

Lectures and practical sessions (Python notebooks).

Grading

- Evaluation of the lab work.
- There will be a final project for students to implement something related to but beyond what we've studied in class.

Learning outcomes covered on the course

- Understand foundational concepts first-order convex optimization - operator splitting, proximal methods, and accelerated methods.
- Familiarity with wavelets, sparse feature learning, and their relation to computer vision.
- Gain expertise in applying optimization techniques to image processing.

Implement practical solutions for image denoising, deblurring, inpainting, super resolution, and stereo matching.

Description of the skills acquired at the end of the course

- Ability to identify and apply suitable first-order optimization techniques to various computer vision tasks (denoising, deblurring, inpainting, etc).
- Capability to implement and modify algorithms for specific computer vision problems.

Comprehensive understanding of the interplay between optimization and computer vision.

3MD3060 – Natural Language Processing

Instructors : **Matthias Galle, Fragkiskos Malliaros**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course will give an overview of the topics of study of the field of *Natural Language Processing*. It will take a problem-centric approach, introducing increasingly complexer problems, starting from basic building blocks like language modeling, tagging and parsing; and progressing towards complex problems like opinion mining, machine translation, question & answering and dialogue. While important historical methods will be mentioned (and studied if still relevant), a focus will be on current state-of-the-art involving many times recent advances in training neural networks and novel architectures.

Quarter number

SG10

Prerequisites (in terms of CS courses)

- Coding skills. All exercises will be done in python
- Knowledge of relevant libraries (scikit-learn, spacy, kears, pytorch, tensorflow) is not required but useful
- Linear algebra
- A basic knowledge of machine learning will be helpful
- Basic computer science concepts

Syllabus

FIRST PART
1. Introduction
2. Language model
3. Representation of words & documents
4. Tagging, Named Entity Recognition
5. Parsing

SECOND PART
6. Mining User Generated Content
7. Machine Translation and Natural Language Generation
8. Machine Reading
9. Dialogue

Class components (lecture, labs, etc.)

Cours magistraux, séances de laboratoire et projet. Le cours se compose de deux sections. La première présente les tâches typiques de la PNL, tandis que la seconde se concentre sur l'application finale.

Grading

The evaluation of the course will be done by three exercises, graded equally. Evaluation will be done mostly automatic (performance on a test set), but qualitative assessment (text file containing explanations, code quality, etc) will also be taken into account.

All projets will be done in groups of not more than 4 students.

Course support, bibliography

The main reference will be Speech and Language Processing. Jurafsky & Martin. Draft of 3rd edition online at https://web.stanford.edu/~jurafsky/slp3/

Learning outcomes covered on the course

The goal of the course is to provide an introduction to the field of Natural Language Processing. By the end of the course, the student will:

- know what are the main applications, why they are challenging and how they can be used
- have grasp of the proven methods and their inner working
- be exposed to current research directions, and have the basic fundamentals to be able to follow the field in the coming years

3MD3070 – Deep Learning for Medical Imaging

Instructors : **Maria Vakalopoulou, Fragkiskos Malliaros**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Medical imaging technologies provide unparalleled means to study structure and function of the human body in vivo. Interpretation of medical images is difficult due to the need to take into account three-dimensional, time-varying information from multiple types of medical images. Artificial intelligence (AI) holds great promises for assisting in the interpretation and medical imaging is one of the areas where AI is expected to lead to the most important successes. In the past years, deep learning technologies have led to impressive advances in medical image processing and interpretation.
This course covers both theoretical and practical aspects of deep learning for medical imaging. It covers the main tasks involved in medical image analysis (classification, segmentation, registration, generative models...) for which state-of-the-art deep learning techniques are presented, alongside some more traditional image processing and machine learning approaches. Examples of different types of medical imaging applications (brain, cardiac...) will also be provided.

Quarter number

SG11

Prerequisites (in terms of CS courses)

There is no official prerequisite for this course. However, the students are expected to have a background in statistics, basic deep learning and computer programming.

Syllabus

- Introduction to medical imaging
- Classification for medical data
- Detection on Medical Imaging
- Segmentation of Medical Imaging
- Validation, Interpretation and reproducibility
- Registration of Medical Volumes
- Denoising and Reconstruction of Medical Imaging
- Generative models

Class components (lecture, labs, etc.)

- 9 x 3h. Depending on the lecture either 3h lecture or 1h30 lecture/ 1h30 TP
- For the practical sessions (TPs) students should bring their personal laptops

Grading

The course will be evaluated through individual assignments and/ or Project including (report, code, oral presentation).

Course support, bibliography

Datasets: Some of the public datasets for medical imaging can be found at:

- https://github.com/beamandrew/medical-data
- https://sites.google.com/site/aacruzr/image-datasets • https://github.com/sfikas/medical-imaging-datasets • https://grand-challenge.org/challenges/

Books:

- I. Goodfellow, Y. Bengio, and A. Courville, “Deep Learning,” 2016.
- Ch. Guy and D. Ffytche“An Introduction to the Principles of Medical Imaging”, 2005.
- T. Hastie, R. Tibshirani and J. Friedman, “The Elements of Statistical Learning,” 2008.
- Ch. M. Bishop,“Pattern Recognition and Machine Learning”, 2006

Related Conferences:

- MICCAI (Medical Image Computing and Computer-Assisted Intervention)
- IPMI (Information Processing in Medical Imaging)
- ISBI (International Symposium on Biomedical Imaging)
- MIDL (Medical Imaging with Deep Learning)

Learning outcomes covered on the course

We expect that by the end of the course, the students will

- have knowledge of state-of-the-art deep learning techniques for medical imaging
- have a deeper understanding of deep learning methods, applicable not only to medical images but also other types of data
- know how to build and validate deep learning models for medical images

3MD3080 – Modern Mathematical Morphology

Instructors : **Fragkiskos Malliaros**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Mathema(cal morphology (MM) is a non-linear theory of image analysis developed from the 1960s at the Ecole des Mines, now Mines Paristech. The main architects of the theory are Georges Matheron and Jean Serra.
The driving idea for MM is to start from set theory and ordering rela(ons instead of linear algebra for its operators. In image processing and computer vision, for many problems, linear algebra is a limita(on. In par(cular, it is difficult to model occlusions. Mathema(cal morphology is useful in many contexts, especially for image analysis, which allows to perform measurements from image data.
The classical theory of MM starts from laKce theory in the con(nuous domain. This causes difficul(es due to topology aspects. A modern descrip(on of mathema(cal morphology starts from graph theory and builds discrete operators. This allows this course to describe seamlessly operators and their mathema(cal proper(es, as well as efficient algorithms and applica(ons.
This course starts from basic operators and finishes with machine learning applica(ons. In par(cular, it is interes(ng to note that Convolu(onal Neural Networks, which combine convolu(on with ac(va(on, can be interpreted as combina(ons of morphological operators.

Prerequisites (in terms of CS courses)

There are few prerequisites for this course. Having followed a graph theory and applica(ons course is very useful; as well as mastering the python language and numpy. Knowledge of the scikit-image, opencv and networkx packages is also useful.

Syllabus

Graphs and operators on graphs; proper(es and algorithms
Basic MM operators: no(on of morphological dila(on and erosion ; Algebraic MM operators; abstract erosion and dila(on
Combina(ons of operators: opening, closing ; extension to weighted graphs ; residues: gradients, top-hat.
Geodesic operators; morphological reconstruc(on; extension to color and mul(spectral operators
Discrete geometry: homotopy-invariant operators, thinning and skeletons
Segmenta(on, graph cuts and watershed operators
Deep learning and MM. Binary neural networks.
Students will implement MM operators from scratch initally, then use the implementation found in scikit-image and OpenCV for applications.

Class components (lecture, labs, etc.)

The course is highly interactive with lectures, tutorials and applications performed simultaneously during a session. There are more lecture elements at the beginning of the course and more applications towards the end.

Grading

The course is evaluated via a short interactive project.

Course support, bibliography

[1] L. Najman and H. Talbot, editors. Mathema(cal Morphology: from theory to applications. ISTE-Wiley, London, UK, September 2010. ISBN 978-1848212152.
[2] Michel SchmiU and JulieUe MaKoli. Morphologie mathématique. Presses des MINES, 2013.
[3] J. Serra. Image Analysis and Mathematical Morphology. Academic Press, 1982.

Description of the skills acquired at the end of the course

Students following this course will gain a better understanding of low-level vision operators and mechanism, as well as the mathematical background behind them.
They will be better able to develop and utilise both designed and learned computer vision pipelines, in particular how linear and non-linear operators can combine to deliver interpretable, coherent, efficient and useful computer vision applications.

3MD3210 – Bayesian Statistics and Applications

Instructors : **Julien Bect, Fragkiskos Malliaros**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The course consists of three parts. The first is devoted to the foundations of Bayesian statistics. Bayesian inference is based on the choice of a Bayesian model, made up of an observations model and a prior probability distribution for the model parameters. Given the observations, we compute what is called the posterior distribution of the parameters of the Bayesian model (using Bayes' rule). The knowledge of this a posteriori law then, allows access to the a posteriori law of the quantities of interest. The second part of the course is devoted to sampling techniques based on Markov chains (Monte Carlo Markov Chains). The third part is devoted to applications of Bayesian inference, in particular to inverse problems. By inverse problem, we mean the determination of a quantity (scalar or vector) from indirect observations (when direct observation of a physical quantity is not possible).

Quarter number

SG10

Prerequisites (in terms of CS courses)

Statistics

Syllabus

- Bayesian Statistics - Parametric models. A priori law. A posteriori law. Average performance of an estimator (loss function, risk). A priori diffuse. A priori conjugates.
- Markov chain sampling - Integration in large dimensions. Basic principles of simulations of a scalar random variable. Acceptance-rejection principle. Principles and variants of the Metropolis-Hastings algorithm. Introduction to Markov chains and elements of analysis of MCMC algorithms.
- Inverse problems - Definition and examples of inverse problems, ill-posed problems. Regularization and classical inversion methods. Bayesian approach to solving inverse problems. Inversion in the Gaussian case and Kalman filters. Variational MCMC and Bayesian approaches. Applications.

Grading

Project work

Course support, bibliography

[1] C. Robert (2004) Monte Carlo Statistical Methods, Springer
[2] C. Robert (2007), The Bayesian Choice, Springer.
[3] A. Mohammad-Djafari (2010), Inverse Problems in Vision and 3D Tomography. Iste-Wiley

Learning outcomes covered on the course

The course will introduce students to the basic principles of Bayesian Statistics and its applications.

3MD3220 – Reinforcement Learning

Instructors : **Fragkiskos Malliaros**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Reinforcement Learning (RL) methods are at the intersection of several fields such as machine learning, probability theory, control theory, or game theory. They study fundamental tradeoffs between exploitation and exploration in order to optimize a future reward in an unknown environment.
Recently, they were successfully applied to many applications such as complex games (Go or Atari), robots control, selection of experts, leading in many cases to super-human performances in those contexts. This class will cover the necessary tools (from a theoretical and practical point of view) to understand how such breakthrough was possible.

Quarter number

SG11

Prerequisites (in terms of CS courses)

The students are expected to be familiar with basic probability concepts, such as Markov Chain, as well as foundations of machine learning concepts.

Syllabus

1. Introduction to RL
2. MDP and Dynamic Programming
3. Bandits
4. Evaluation tools
5. Control tools
6. RL with approximations
7. Delving into Deep RL

Class components (lecture, labs, etc.)

Each section of the course will be either 1h30' lecture or 1h30' lab. The labs will include practical sessions and small projects in python and will provide the students the opportunity to test the theoretical concepts on toy examples.

Grading

The evaluation of the course will be based on the following:
- Assignments: the assignments will include theoretical questions as well as practical codes that should run on jupyter notebooks.
- Project: The students are expected to form groups of 2-3 people, propose a topic for their project (that will have to be validated), and submit a final project report.

Course support, bibliography

• Sutton & Barto, Reinforcement Learning: An Introduction
• Szepesvari, Algorithms for Reinforcement Learning
• Bertsekas, Dynamic Programming and Optimal Control, Vols I and II
• Puterman, Markov Decision Processes: Discrete Stochastic Dynamic Programming

Learning outcomes covered on the course

The course aims to introduce students to understand the underlying concepts of reinforcement learning algorithms. Beyond the theory, the students will have the opportunity to practice Reinforcement Learning via lab sessions.

3MD3230 – Advanced Multivariate Data Analysis

Instructors : **Fragkiskos Malliaros, Arthur Tenenhaus**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Standard statistical methods allow the analysis of an individuals × variables data table. This data structure is often too limited to represent more complex data. For example, let us mention (i) data of a tensorial nature where the same variables are observed according to several modalities (e.g., spatio-temporal data) or (ii) multi-table data where individuals are characterized by variables of a heterogeneous (e.g., imaging-genetic data).

This course provides an overview of the methods that allow the analysis of such types of complex data.

Prerequisites (in terms of CS courses)

Basic knowledge of statistics, optimization, linear algebra

Syllabus

- Tensor data (PARAFAC, Tucker, Coupled Matrix Tensor Factorization, Tensor Regression, etc ...)
- Multiblock data (Regularized generalized canonical analysis and special cases)
- Kernel methods (e.g., PCA kernel, GCCA kernel).
- Structural Equation Models (SEM)

Class components (lecture, labs, etc.)

The methods presented in class will be implemented using R or Python software.

Grading

Projects

Course support, bibliography

Adachi, K. (2016). Matrix-based introduction to multivariate data analysis. Springer

Learning outcomes covered on the course

The students will acquire know-how that allows the statistical analysis of data with complex structures (e.g., multi-table or tensor data).

3MD3250 – Deep Learning in Practice

Instructors : **Fragkiskos Malliaros**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Deep learning methods are now the state of the art in many machine learning tasks, leading to impressive results. Nevertheless, they are still poorly understood, neural networks are still difficult to train, and the results are black-boxes missing explanations. Given the societal impact of machine learning techniques today (used as assistance in medicine, hiring process, bank loans...), it is crucial to make their decisions explainable or to offer guarantees. Besides, real-world problems usually do not fit the standard assumptions or frameworks of the most famous academic work (data quantity and quality, expert knowledge availability...). This course aims at providing insights and tools to address these practical aspects, based on mathematical concepts.

Quarter number

SG11

Prerequisites (in terms of CS courses)

The only prerequisite for this course is the introduction to Deep Learning course by Vincent Lepetit (taking place during the 1st semester), as well as coding skills in python (as exercises will be in PyTorch). However, the students are expected to have some notions in information theory, Bayesian statistics, analysis, differential calculus.

Syllabus

1. Introduction: gap between practice and theory
2. Interpretability
3. Small data and robustness
4. Towards real-world problems: from synthethic Reinforcement Learning to robots
5. Scaling Deep learning
6. Auto-DeepLearning
7. Guest lectures from the Industry

More detailed content
This class will start by emphasizing theoretical misconceptions, by exhibiting cases where neural networks do not reach classical techniques' performance, and also, on the opposite, explicit cases of deep learning success with proofs of depth requirement.
We will then study different ways to visualize what a neural network is doing, in order to interpret its decisions, and check that it does neither reproduce undesired biases present in the dataset (such as sensitivity to ethnicity when matching CVs to job offers), nor disclose private information from people in the dataset.
The rest of the course will investigate practical issues when training neural networks, in particular data quantity, trials to apply deep learning to real Reinforcement Learning problems, and automatic hyper-parameter tuning.
The last lesson will be a set of lectures by guests from different domains of the Industry, as a showcase of successful applications of deep learning, with practical recommendations.

Class components (lecture, labs, etc.)

Lectures and excercices.

Grading

The course sessions will comprise practical exercises (three mini-projects total, in PyTorch), which will be evaluated.

Course support, bibliography

1. *Deep Learning*, Ian Goodfellow and Yoshua Bengio and Aaron Courville, 2013
2. *Why does deep and cheap learning work so well?,* Henry W. Lin, Max Tegmark, David Rolnick
3. *Learning from Simulated and Unsupervised Images through Adversarial Training*, Ashish Shrivastava, Tomas Pfister, Oncel Tuzel, Josh Susskind, Wenda Wang, Russ Webb

More references can be found on the webpage of the course.

Learning outcomes covered on the course

The course aims to introduce students to common issues in daily deep learning practice. We expect that by the end of the course, the students will be able to better grasp the potential problems and better define their training setup.

3MD3260 – Machine Learning in Network Science

Instructors : **Fragkiskos Malliaros**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Networks (or graphs) have become ubiquitous as data from diverse disciplines can naturally be mapped to graph structures. Social networks, such as academic collaboration networks and interaction networks over online social networking applications are used to represent and model the social ties among individuals. Information networks, including the hyperlink structure of the Web and blog networks, have become crucial mediums for information dissemination, offering an effective way to represent content and navigate through it. A plethora of technological networks, including the Internet, power grids, telephone networks and road networks are an important part of everyday life. The problem of extracting meaningful information from large scale graph data in an efficient and effective way has become crucial and challenging with several important applications and towards this end, graph mining and analysis methods constitute prominent tools. The goal of this course is to present recent and state-of-the-art methods and algorithms for analyzing, mining and learning large-scale graph data, as well as their practical applications in various domains (e.g., the web, social networks, recommender systems).

Prerequisites (in terms of CS courses)

There is no official prerequisite for this course. However, the students are expected to:

- Have basic knowledge of graph theory and linear algebra.
- Be familiar with fundamental data mining and machine learning tasks.
- Be familiar with at least one programming language (e.g., Python or any language of their preference).

Syllabus

- Introduction to network science and graph mining; basic network properties.
- Random graphs and the small-world phenomenon; power-law degree distribution and the Preferential Attachment model.
- Centrality criteria and link analysis algorithms.
- Graph clustering and community detection.
- Node similarity and link prediction.
- Graph similarity.
- Representation learning on graphs.
- Epidemic processes and cascading behavior on networks; influence maximization in social networks.

Class components (lecture, labs, etc.)

Each section of the course is divided into 1h30' lecture and 1h30' lab. The labs will include hands-on assignments (using Python) and will provide the students the opportunity to deal with graph mining tasks in practice.

Grading

The evaluation of the course will be based on two projects.

Course support, bibliography

Most of the material of the course is based on research articles. Some of the topics are also covered by the following books:

- David Easley and Jon Kleinberg. Networks, Crowds, and Markets. Cambridge University Press, 2010.
- William L. Hamilton. Graph Representation Learning. Morgan and Claypool Publishers. 2020.
- Mark E.J. Newman. Networks: An Introduction. Oxford University Press, 2010.
- Deepayan Chakrabarti and Christos Faloutsos. Graph Mining: Laws, Tools, and Case Studies. Synthesis Lectures on Data Mining and Knowledge Discovery, Morgan and Claypool Publishers, 2012.
- Reza Zafarani, Mohammad Ali Abbasi, and Huan Liu. Social Media Mining. Cambridge University Press, 2014.
- Albert-Laszlo Barabasi. Network Science. Cambridge University Press, 2016.

Relevant conferences:

- NeurIPS: Neural Information Processing Systems
- ICML: International Conference on Machine Learning
- ICLR: International Conference on Learning Representations
- SIGKDD: ACM SIGKDD International Conference on Knowledge Discovery and Data Mining
- AAAI: Association for the Advancement of Artificial Intelligence
- IJCAI: International Joint Conference on Artificial Intelligence
- ICDM: International Conference on Data Mining
- WWW: International World Wide Web Conferences
- WSDM: International Conference on Web Search and Data Mining

Resources

Lectures, lab sessions, team projects

More information can be found at the website of the course: https://fragkiskos.me/teaching/MLNS-S24

Learning outcomes covered on the course

The course aims to introduce students to the field of graph mining and network analysis by:

- Covering a wide range of topics, methodologies, and related applications.
- Giving the students the opportunity to obtain hands-on experience in dealing with graph data and graph mining tasks.

Description of the skills acquired at the end of the course

We expect that by the end of the course, the students will have a thorough understanding of various graph mining and learning tasks, will be able to analyze large-scale graph data as well as to formulate and solve problems that involve graph structures.

3MD3270 – Data visualization

Instructors : **Fragkiskos Malliaros, Petra ISENBERG**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (PARIS-SACLAY), DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

As the amount of data is growing faster than the speed of computers to process them, it becomes harder to analyze this data, to understand it both at a global level and at a smaller scale, and to make decisions based on the data. Visualization turns data into visual representations that allow users to understand it and to provide them with interactive tools that are designed to efficiently navigate and analyze these representations. The class introduces students to the field of visualization, discusses various types of visualizations according to the type of data being analyzed (tabular data, hierarchical data, graphs, texts, 3D data), and teaches the process to build data analysis tools.

Prerequisites (in terms of CS courses)

There is no official prerequisite for this course. However, to be successful in the class the students are expected to:

- have basic knowledge of programming
- be able to work with basic data tables (CSV) using standard tools such as MS Excel or LibreOffice
- be able and willing to learn a new data processing/visualization API, and independently debug code and solve issues using online resources.

Syllabus

1. General class introduction, introduction to information visualization
2. Perception and color
3. Multi-dimensional data visualization
4. Graphs and trees
5. Interaction
6. Storytelling with data
7. Text visualization
8. 3D data visualization

Class components (lecture, labs, etc.)

Each lecture block comprises a 1h30' lecture and a 1h30' lab. The lectures introduce basic concepts, while in the labs the students do practical exercises and are introduced to the assignments they complete in-between meetings.

Grading

We evaluate the course as follows:

- Assignments: The assignments are practical exercises done in groups, based on the material taught in the lectures. They have to be submitted between two meetings, and will be peer-reviewed. Students are graded on their participation in this peer feedback process. Assignments have to be handed in on time, otherwise students do not receive feedback and lose points.
- Project presentation: The final result of the assignment series is presented, and the presentation and the project itself are graded.

- Final exam: multiple-choice exam based on the lecture material.

We split the overall grade as follows:

- Peer feedback participation, on-time assignment submission: 10%
- Final group project and its presentation: 40%
- Final exam: 50%

Course support, bibliography

- Datasets: varying, to be chosen by the students Software tools for data visualization: https://p5js.org/, https://plotly.com/, https://matplotlib.org/, and similar
- Related conference: IEEE Conference on Visualization http://ieeevis.org/
- Related courses: computer graphics, human-computer interaction, visual analytics, scientific visualization

Resources

Assignments, project presentations, final exam.

Learning outcomes covered on the course

To understand the need for visualization to make sense of data

- to understand different data types and their visualization needs
- to understand the implications of the human visual system for visualization
- to get to know different types of visual representations
- to understand the need for and potential of interactivity for visualization
- to get practical experience through a group project, developing a visualization tool for a self-chosen dataset

Description of the skills acquired at the end of the course

We expect that by the end of the course, the students will have a thorough understanding of data visualization techniques.

3MD3500 – MDS Project

Instructors : **Erick Herbin, Fragkiskos Malliaros, Pauline Lafitte**
Department : **DOMINANTE - MATHÉMATIQUES, DATA SCIENCES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

See http://math.centralesupelec.fr/sites/math/files/inline-files/projet_recherche_MDS_2023-2024.pdf

Prerequisites (in terms of CS courses)

No

Learning outcomes covered on the course

See the online document.

3MD4010 – Algorithms in data science

Instructors : **Frederic Pennerath**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **22,50**

Description

This course presents some algorithmic building blocks that are particularly useful and efficient to process data. First, the course introduces techniques of variational inference and sampling that are used in statistics to estimate approximatively parameters of the most complex models. These techniques are implemented during labworks on examples of growing complexity, using Pytorch as used in the Deep Learning course. As a complement, the course presents different topics such as the architecture and algorithms of search engines and recommendation systems, the social network analysis or data structures used in data sketching to analyse large data streams.

Quarter number

SG10

Prerequisites (in terms of CS courses)

To have completed the "Automatic Learning" and "Statistical Models 1" courses

Syllabus

Volume: 13.5h of lectures, 9h of labworks

Lectures:
- Variational inference and sampling algorithms (4.5h)
- Applications: Bayesian Deep Learning and Variational AutoEncoders (3h)
- Algorithms of recommender systems (1.5h)
- Social network analysis algorithms (1.5h)
- Data stream analysis algorithms (1.5h)

Labworks:
- Sampling exercises 1/2
- Sampling exercises 2/2
- Statistical programming 1/4
- Statistical programming 2/4
- Statistical programming 3/4
- Statistical programming 4/4

Class components (lecture, labs, etc.)

Each class session lasts 1.5 hours and is followed by a 1.5-hour labwork session to apply some of the concepts seen in class.
Programming in Python.

Grading

Students will participate in team to a data science challenge. Deliverables will be a 30 minutes long video presenting the problem, solution and results along with documented code. The evaluation will focus on the added value of the bibliographic work, the relevance of design choices, the quality of the implementation and the project management.

Course support, bibliography

- Course presentation materials.
- "Introduction to Information Retrieval", C. Manning, P. Raghavan and H. Schütze, (Cambridge University Press, 2008)
- "Mining of Massive Datasets", J. Leskovec, A. Rajaraman, JD Ullman (Cambridge University Press, 2014)
- "Algorithmic aspects of machine learning", A. Moitra (Cambridge University Press, 2018)

Resources

- Teachers: Frédéric Pennerath (Course, TD, TP), Mohammed Fellaji (TP)
- TP on Linux / Python PC
- 2 groups of TPs
- 2 students max per PC

Learning outcomes covered on the course

- Implement approximate techniques to leverage complex statistical models.
- Understand the general context as well as the principles of the algorithms used in different fields of data processing such as information retrieval, recommendation systems, social network analysis or data flow processing.

Description of the skills acquired at the end of the course

- C1.3 - Solve the problem with approximation, simulation and experimentation
- C6.5 - Use all types of data, structured or unstructured, including massive
- C6.6 - Understanding the digital economy

3MD4020 – Sound processing (speech and music)

Instructors : **Stephane Rossignol**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **35**
On-site hours (HPE) : **20,00**

Description

The purpose of this lecture is to expose the body of methods of analysis of musical and speech sound signals. The analysis, the modeling, the synthesis, the coding and speech recognition are treated. Measures, annexes but necessary for the methods described above, are also studied: the pitch, the voicing, the calculation of the MFCC, the calculation of the DTW, the detection of vocal activity... Some methods of spectral analysis must be studied in depth.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Signal processing (1CC400)
Statistics and machine learning (1CC5000)
Programming experience (1CC1000)

Syllabus

Lecture, 9h
1. introduction (sound perception and production)
2. spectral analysis for sound analysis (non-parametric/AR(ARMA)/eigenspace method)
3. speech modelling and analysis
4. speech recognition
5. speech recognition (Deep learning)
5. speech synthesis and coding, speech activity detection (SAD), speaker recognition, human-machine dialog, speech/music pitch tracking, voicing decision, ...
7. conclusion

Tutorials/Labs, 9h
1. implementation of the method PSOLA (Pitch Synchronous Overlap and Add), plus SAD and/or pitch tracking and/or voicing decision
2. implementation of a complete recognition system : MFCC+DTW
3. implementation of a complete recognition system : Deep learning (RNN et LSTM)

Exam: the Labs

Class components (lecture, labs, etc.)

9h Lecture
9h Tutorials/Labs: 3 Labs, 3 hours each

Grading

Continuous monitoring (50%; individual score) and oral presentation at the very end of the labs (50%). Labs : grading by pair; differentiated in the event of an anomaly in a pair.

Course support, bibliography

Slides

Resources

- Teacher : Stéphane Rossignol
- Room size for tutorials : 34
- Max room size for labs : 34
- Software : Matlab (34 licences)/Octave/Python
- Rooms for labs : rooms on Metz campus

Learning outcomes covered on the course

- Design a complete signal processing chain.
- Compare the performances of the various tools at our disposal for the analysis of complicated time series, in order to choose the one which will be best suited for this or that signal to be analyzed.
- Program in an interpreted computer language (matlab/octave/python/...).
- Mastering the basic and advanced principles of analog signal processing and digital signal processing.

Description of the skills acquired at the end of the course

- C1.1 : Examine a problem in full breadth and depth, within and beyond its immediate parameters, thus understanding it as a whole. This whole weaves the scientific, economic and social dimensions of the problem.
- C2.3 : Rapidly identify and acquire the new knowledge and skills necessary in applicable domains, be they technical, economic or others.
- C3.6 : Evaluate the efficiency, feasibility and strength of the solutions offered.
- C9.4 : Demonstrate rigour and critical thinking in approaching problems from all angles, be they scientific, social or economic.

3MD4030 – Image processing

Instructors : **Jean-Luc Collette**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **35**
On-site hours (HPE) : **20,00**

Description

This course is intended to give an overview of image processing.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Signal processing, random signal representation.

Syllabus

Image sensor (optical quantities), sampling and digitization, transformations on images, attributes on images, classification.

Class components (lecture, labs, etc.)

Lectures and practical works alternately.
Lectures : 7x1h30
Practical work : 3x3h00

Grading

Written report of practical work.

Course support, bibliography

Petrou M. "Image processing : The fundamentals" – John Wiley & sons 2003.
Rosenfeld A. "Multiresolution image processing and analysis" – Springer-Verlag 1984.
Pratt W. "Digital Image Processing" – John Wiley & sons 1978.

Resources

Associate Professor for practical work: Jean-Louis Gutzwwiller. Software: Matlab and Python.

Learning outcomes covered on the course

- be able to extract and exploit the data contained in the images
- be able to analyze images by choosing appropriate methods

Description of the skills acquired at the end of the course

C3.7 Make pragmatic and informed choices with the aim of producing tangible results.
C6.4 Solve problems through mastery of computational thinking skills.

3MD4040 – Deep learning

Instructors : **Jeremy Fix**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Deep learning is a technology that is booming, thanks in particular to the use of GPUs (Graphical Processing Units), the availability of large amounts of data and the understanding of theoretical elements that make it possible to better define neural network architectures that are more easily trainable. In this course, students will be introduced to the basics of neural networks and also to the different architectural elements that make it possible to design a neural network according to the prediction problem considered. The course is divided into modules in which questions of optimization algorithms, their initialization, regularization techniques, fully connected architectures, convolutional networks, recurrent networks, introspection techniques are addressed. Practical works on GPUs are associated with the courses.

Quarter number

SG10

Prerequisites (in terms of CS courses)

We expect the students to have basic knowledge in linear algebra, optimization, computer vision and python programming. The students are expected to be handful in Linux.

Syllabus

The lectures will be discussing :

- Historical introduction to neural networks, linear classifer/regressor (1.5 HPE)
- Computational graph and gradient descent, Fully connected networks, RBFs, Auto-encoders, Optimization algorithms, initialization, regularisation (3 HPE)
- Convolutional neural networks : architectures (1.5 HPE)
- Convolutional neural networks: classification, object detection, semantic segmentation (1.5 HPE)
- Recurrent neural networks: architectures and training (1.5 HPE)
- Recurent neural networks: applications (1.5 HPE)
- Introduction to generative and probabilistic networks (RBM, Deep Belief Networks) (1.5 HPE)

The praticals will be on:
- Introduction to pytorch on classification with linear predictors, fully connected networkjs and convolutional networks (3 HPE)
- Convolutional neural networks for semantic segmentation (3 HPE)
- Recurrent neural networks applied to sequence to sequence translation (3 HPE)
- Adversial neural networks (3 HPE)

Class components (lecture, labs, etc.)

The course is structured into lectures during which we introduce the theoretical and experimental notions are introduced and illustrated with various examples. Practicals allow the students to put into practice the notions we discuss during the lectures.

Grading

The students will participate to a dedicated challenge in a team. The grade depends both on their submission, and a recorded video explaining their approach and results.

Course support, bibliography

- Deep learning book, Ian Goodfellow, Aaron Courville, and Yoshua Bengio, MIT Press : http://www.deeplearningbook.org/
- CS231n, Stanford, http://cs231n.stanford.edu/
- Practical deep learning for coders : https://course.fast.ai/

Resources

- Jérémy Fix, Teacher, supervisor during the practicals
- Joël Legrand, supervisor during the practicals

We will be using the Pytorch framework. The students could work in pairs and will make use of GPUs of the Data Center d''Enseignement of the Metz campus for running their codes.

A page will be dedicated on edunao. Forums will be opened, allowing the students to ask questions on the lectures or the tutorials, having the possibility to interact with the teaching staff but between them as well.

Learning outcomes covered on the course

- Being able to implement and deploy a deep learning algorithm
- Being able to choose the right architecture that suits a particular machine learning problem
- Being able to diagnose the training of a neural network (what is it learning ? how is it learning ? is it learning ? will it be able to generalize ?)

Description of the skills acquired at the end of the course

- C1.4, Milestone 2
- C3.6, Milestone 1
- C3.7, Milestone 2

3MD4050 – Statistical models 2 - MTZ

Instructors : **Frederic Pennerath**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **29,00**

Description

The courses "Statistical Models for Automatic Learning" ModStat1 and ModStat2 address the problem of automatic learning from the perspective of probabilistic models and statistical estimation.
While the courses present the most useful models and methods in this context, they are not intended to be an exhaustive catalog.
The objective is more to present within a coherent theory the theoretical concepts and tools common to all these models and methods and to show how, based on modeling assumptions specific to each type of problem addressed, these concepts are logically assembled before arriving at an operational learning method.
The challenge is not only to empower students to understand and use existing models wisely, but also to design new models (or adapt existing models) to address the particularities of new problems.
The courses will also aim to achieve a continuum from theory to practice, whether in class or in TP: the hypotheses associated with a given class of problems are first identified, followed by theoretical modeling work, which leads to the definition of a model and its estimation algorithms. These results are then implemented (in Python) and evaluated on data.
Course ModStat1 will introduce the basic tools of statistical modelling while course ModStat2 will focus on models based on hidden variables.

Quarter number

SG10

Prerequisites (in terms of CS courses)

- Basic knowledge of probability theory, statistics and machine learning
- Beginner level in Python / Numpy programming

Syllabus

Total length : 12h of lectures, 3h of tutorials, 12h of labworks and 2h of written exam

Lectures (12h)
- Gaussian processes (1.5h)
- Hidden variable models and EM algorithm (1.5h)
- Mixture models. Example of Gaussian mixtures (GMM) (1.5h)
- Markov processes and chains, hidden Markov models (3h)
- Kalman filter, EKF, UKF and particle filters (3h)
- Causality (1,5h)

Tutorials (3h)
- HMM (1,5h)
- Kalman filters (1,5h)

Labworks (12h)
- Gaussian processes (3h)
- Mixture models (3h)
- HMM (3h)

- Kalman and particle filters (3h)

Written exam (2h)

Class components (lecture, labs, etc.)

- The courses use demos or examples to illustrate abstract concepts.
- Tutorials (1.5h) and labworks on computers (3h) give the opportunity to apply notions seen during lectures from both theoretical and practical perspectives.

Grading

Written exam of 2 hours with handouts on solving statistical modeling exercises and problems.

Course support, bibliography

- Course material (Course presentation, handout)
- "Machine Learning – A Probabilistic Perspective", Kevin Murphy (MIT Press, 2012)
- "Bayesian Reasoning and Machine Learning", David Barber (Cambridge University Press, 2012)
- "All of Statistics: A Concise Course in Statistical Inference", Larry Wasserman (Springer-Verlag, 2004)

Resources

- Teachers: Frédéric Pennerath (lectures, exercise sessions, labworks), Joël Legrand (labworks)
- Programming with Python and its standard libraries.
- 1 group fur exercise sessions
- 2 groups for labworks
- 2 students max per PC

Learning outcomes covered on the course

- Be able to choose a statistical model/method adapted to the problem under consideration and implement it appropriately
- Be able to understand the theoretical concepts underlying a statistical inference method presented in a scientific article.
- Be able to implement a model / statistical method in a language such as Python.
- Be able to adapt a model/method to take into account the specificities of the problem being addressed.

Description of the skills acquired at the end of the course

C1.2 - Use and develop appropriate models, choose the right modeling scale and relevant simplifying assumptions to address the problem
C2.1 - Have studied in depth a field or discipline related to the basic or engineering sciences
C6.4 - Solving problems in a computational thinking process

3MD4110 – GPU Programming

Instructors : **Stephane Vialle**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **20,00**

Description

This course aims to introduce high performance algorithmics and programming on GPU, with experiments on Machine Learning algorithms run on GPU servers.

Quarter number

SG11

Prerequisites (in terms of CS courses)

- 1st year common course: "Systèmes d'Information et Programmation" (1CC1000)
- 1st year common course: "Algorithmique & Complexité" (1CC2000)
- C++ Advanced programming course (3MD1020) of SDI mention at Metz
- Automatic Learning course (3MD1040) of SDI mention at Metz

Syllabus

- GPU architecture
- Algorithmic principles of fine grained GPU parallelism (SIMD and SIMT models)
- CUDA programming
- Optimization of GPU and CPU-GPU CUDA codes
- Design and experiment of K-means algorithms on GPU

Class components (lecture, labs, etc.)

Course organized in 3 parts:

- 2 parts about CUDA development (basic and advanced concepts), including courses and experiments on machines
- 1 part on the development in CUDA of a K-means algorithm, including a tutorial and experiments on machines

Overall distribution: Lectures: 6h00, Tutorials: 2h30, Labs: 11h30 (total of 20 HPE)

Lesson plan:

- Part 1: GPU architecture, and CUDA algorithmics and programming principles
    - Lectures: 3h00, Tutorials: 1h30, Labs: 3h00
- Part 2: CUDA code optimization, and library usage
    - Lectures: 3h00, Labs: 3h00
- Part 3 : K-means on GPU
    - Tutorial: 1h00, Labs Part-1: 2h30, Labs Part-2: 3h00

Grading

Evaluation of Lab results about parts 2 and 3, and final and individual exam

- **Reports of the Lab about parts 2 and 3** (the content and the number of pages of the reports are constrained, in order to force the students to an effort of synthesis and clarity)
- In the event of unjustified absence from a practical work, the mark of 0 will be applied, in the event of justified absence the average mark of other labs will be applied.
- The remedial exam will be a 1 hour oral exam, which will constitute 100% of the remedial mark.

Course support, bibliography

- Slides of the teacher
- J. Sanders and E. Kandrot. "CUDA by Example: An Introduction to General-Purpose GPU Programming". NVIDIA. 2010.

Resources

- Teatching team: **Stephane Vialle.**
- Development and execution platform: **GPU servers of the Data Center for Education of CentraleSupélec Metz Campus.**
- **NVIDIA CUDA** development environment.

Learning outcomes covered on the course

At the end of this course, students will be able:

- **Learning Outcome AA1:** to analyse the adequacy of a mathematical solution with an implementation and execution on GPU,
- **Learning Outcome AA2:** to design a GPU algorithm, or to adapt an algorithm to increase its efficiency on GPU,
- **Learning Outcome AA3:** to design hybrid algorithms for CPU-GPU systems, overlapping data transfers and computations,
- **Learning Outcome AA4:** to implement algorithms and to debug codes on GPU,
- **Learning Outcome AA5:** to analyse and to summarize GPU software.

Description of the skills acquired at the end of the course

Design of GPU algorithms and codes remains original, and needs:

- **to improve the following skills:**
    - **C6.3:** Conceive, design, implement and authenticate complex software
        - ***Marker 3*****:** parallel software development (massively parallel software running on GPU)
        - Related to Learning Outcomes **AA2, AA3, AA4**
    - **C6.4:** Solve problems through mastery of computational thinking skills
        - ***Marker 2*****:** exploitation of parallel architectures (fine grained and massively parallel GPU architecture)
        - Related to Learning Outcomes **AA1**
- **to know how to clearly introduce his/her original sotware approach to his/her colleagues:**
    - **C7.1:** Persuade at core value level; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. Highlight the added value
        - ***Marker 1***: evaluated from a report or a solution introduction during classical learning
        - Related to Learning Outcomes **AA5**

3MD4120 – Reinforcement learning

Instructors : **Herve Frezza-Buet**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **23,00**

Description

The course presents the theoretical foundations of reinforcement learning as well as the principles of the most common algorithms. Through practical work, these elements will be extended to more complex situations, making it possible to introduce the most recent algorithms that have, for example, enabled computers to master the game of Go.

Quarter number

SG11

Prerequisites (in terms of CS courses)

This course requires basic notions of linear algebra and probability theory. For practical work, a good knowledge of python (numpy) is required. The last TP is based on a practical mastery of deep learning with pytorch.

Syllabus

Reinforcement learning is introduced using the formal framework of the Markov Decision Processes. After having shown the existence and uniqueness of a solution in the form of the value function, we will discuss the classical algorithms used to calculate this function. We will then see how approximate methods (linear approximation, monte carlo estimation, bandits, deep learning) can be used to tackle more complex contexts.

Class components (lecture, labs, etc.)

Taking into account the context (group size), lectures will be as interactive as possible andd will aim to present the theoretical and algorithmic concepts underlying reinforcement learning. The purpose of the practical work is to really confront the methods by implementing and testing the algorithms to better understand how they work and their limitations.

Grading

The module will be evaluated by a written exam, where the idea is to test the student's ability to use methods in a clever way, to analyze the results of an algorithm, etc.

Course support, bibliography

The course is accompanied by a written support in English, in which the bibliographical references of the field are cited.

Resources

Courses and practical work are provided by Alain DUTECH, Hervé FREZZA-BUET and Jérémy FIX. The practical work will be based on the Python language and its scientific libraries.

Learning outcomes covered on the course

- Understand the theoretical foundations of reinforcement learning.
- Implement these methods in a way that is adapted to the problems to be solved.
- Sharpen your critical thinking skills.

Description of the skills acquired at the end of the course

C3.5, Marker 1: Put forward new tools with either continual progress or disruptive solutions as the goal
C3.6, Marker 1: Evaluate the efficiency, feasibility and strength of the solutions offered. / proposed solutions.
C3.7, Marker 2: Make pragmatic and informed choices with the aim of producing tangible results.

3MD4130 – Big Data computing models

Instructors : **Stephane Vialle**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **21,00**

Description

The goal of this course is to teach students how to develop high-performance data analysis applications in the Spark environment on distributed platforms (clusters and clouds). Distributed file system mechanisms such as HDFS will be studied, as well as Spark's extended map-reduce programming model and algorithmic on top of Spark "RDD", followed by higher-level programming models on top of Spark "Data Frames", and finally programming models on Clouds. Scaling criteria and metrics will also be studied. Throughout the course, implementations will take place on clusters and in a Cloud, and the developed solutions will be evaluated by the performance obtained on test cases, and by their ability to scale.

Quarter number

SG11

Prerequisites (in terms of CS courses)

- Common 1st year course "Systèmes d'Information et Programmation" (1CC1000)
- Common 1st year course "Algorithmique & Complexité" (1CC2000)
- "Ingénierie des données et du logiciel" course (3MD1510) of SDI mention at Metz

Syllabus

- Emergence of Big Data technologies: motivations, industrial needs, main players.
- Hadoop software stack, architecture and operation of its distributed file system (HDFS)
- Spark distributed computing architecture and deployment mechanism
- Spark "RDD" programming model and algorithmics of Spark extended map-reduce
- Spark "Data Frames" programming model applied to graph analysis (GraphX module)
- Architecture et environnement d'analyse de données sur Cloud
- Experiments and performance measures
- Performance criteria and metrics

Class components (lecture, labs, etc.)

This course links 3 parts relating to "Big Data" computing models: the first on PC clusters, the second in the Cloud, and the third which assesses "scaling-up" solutions.

Global organization: Courses: 10h30, Exercises: 1h30, Labs: 9h00 (total 21,00 HPE)

Course plan in 4 parts:

- Part 1: Software architecture and development with Spark RDD on top of HDFS and PC clusters.
    - Lectures: 4h30, Tutorials: 1h30, Labs: 3h00
- Part 2: Criteria and metrics for performance and scaling.
    - Lectures: 1h30
- Part 3: Large scale computation and data analysis on *Cloud*.
    - Lectures: 3h00, Labs: 3h00
- Part 4: Development with Spark Data Frames on top of HDFS and PC clusters.

- Lectures: 1h30, Labs: 3h00

Grading

Evaluation from Labs:

- **The reports of the Labs will be evaluated** (the content and the number of pages of the reports will be constrained, in order to force the students to an effort of synthesis and clarity)
- In case of unjustified absence from a practical course, a mark of 0 will be applied; in case of justified absence, the practical course will not be included in the final mark.
- The remedial exam will be a 1 hour written exam, which will constitute 100% of the remedial mark.

Course support, bibliography

- Slides of the teachers
- BdD NoSQL :
  - Kristina Chorodorw. MongoDB. The Definitive Guide. 2nd edition. O'Reilly. 2013.
  - Rudi Bruchez. Les bases de données NoSQL et le Big Data. 2ème édition. Eyrolles. 2016.
- Hadoop & Map-Reduce :
  - Tom White. Hadoop. The definitive Guide. 3rd edition. O'Reilly. 2013.
  - Donald Miner and Adam Shook. MapReduce Design Patterns. O'Reilly. 2013.
- Spark :
  - M. Zaharia, M. Chowdhury, T. Das, A. Dave, J. Ma, M. McCauley, M.J. Franklin, S. Shenker, and I. Stoica. Resilient Distributed Datasets : A Fault-tolerant Abstraction for In-memory Cluster Computing. In Proceedings of the 9th USENIX Conference on Networked Systems Design and Implementation, NSDI'12, 2012.
  - H. Karau, A. Konwinski, P.Wendell, and M.Zaharia. Learning Spark. O'Reilly, 1st edition, 2015.
  - H. Karau and R. Warren. High Performance Spark. O'Reilly, 1st edition, 2017.

Resources

- Teaching team: **Stéphane Vialle** and **Gianluca Quercini** (CentraleSupelec), **Wilfried Kirschemann** (ANEO)
- Development and execution plateform:
  - **computing clusters of the Data Center for Education (DCE)** of CentraleSupelec Metz campus
  - **access to a professional cloud**
- Development environment:
  - **Spark+HDFS on DCE machines**
  - **other environment on Cloud ressources**

Learning outcomes covered on the course

After this course, students will be able:

- **Learning Outcome AA1:** to design and implement extended map-reduce algorithms, powerful and scaling on distributed platforms,
- **Learning Outcome AA2:** to analyse the scaling capabilities of an application,
- **Learning Outcome AA3:** to use a cluster or a cloud to achieve large scale data analysis,
- **Learning Outcome AA4:** to synthetically present a data analysis solution designed on top of a "map-reduce" model.

Description of the skills acquired at the end of the course

Design of algorithms and implementation of codes with scaling capabilities allow to:

- extend the acquisition of 2 skills:
  - **C6.3**: Conceive, design, implement and authenticate complex software
    - ***Marker 3*** : Parallel software development (considering large scale "Big Data" software)
    - According to the Learning Outcomes **AA1**, **AA2**
  - **C6.4:** Solve problems through mastery of computational thinking skills

        - *Marker 2* : Exploitation of parallel architectures (considering large scale distributed architectures for "Big Data")
        - According to the Learning Outcomes AA3
- acquire a skill allowing to present clearly an original software approach
    - **C7.1:** Persuade at core value level; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. Highlight the added value.
        - **Marker 1**: evaluated from a report or a presentation of a solution within the framework of "classic" lessons
        - According to the Learning Outcomes AA4

3MD4140 – Statistical learning

Instructors : **Michel Barret**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **23,00**

Description

The objective of supervised learning is to propose methods that, based on a training set of examples, make a decision on a parameter based on observations, the decision being the best possible on average. For example, classify images according to their content, i.e. decide if an image represents a cat, a dog, or something else. We will formally present the problem and study the guarantees of generalization of supervised learning algorithms, i.e. the quality of prediction of the output associated with an entry not present in the training set. To achieve this objective, we will introduce the concepts of hypothesis space with PAC (probably approximately correct) learning capacity , Vapnik-Chervonenkis dimension of a hypothesis space. We will state and prove two fundamental theorems of supervised learning theory giving a lower bound and an upper bound of the real risk to the binary classification problem.

Quarter number

SG11

Prerequisites (in terms of CS courses)

- Probability 1A (CIP-EDP, 1SL1000)
- Statistics, Machine learning and Data processing ST4 (1CC5000),

Syllabus

- Formalization of supervised learning problems
- PAC learning capacity and uniform convergence
- The bias-complexity trade-off
- The VC (Vapnik-Chervonenkis) dimension of a hypothesis space
- Two fundamental theorems of PAC learning

Class components (lecture, labs, etc.)

10,5h of courses + 10,5h of tutorials + written exam of 2h

Grading

written exam of 2h with documents

Course support, bibliography

S. Mallat, L’apprentissage face à la malédiction de la grande dimension, Cours du Collège de France, 2018.

S. Shalev-Shwartz and S. Ben-David, Understanding Machine Learning, from theory to algorithms, Cambridge University Press, 2014.

O. Catoni, Comment: Transductive PAC-Bayes Bounds Seen as a Generalization of Vapnik–Chervonenkis Bounds, *Measures of Complexity, Festschrift for Alexey Chervonenkis*, chap 10, Springer, 2015.

Resources

The tutorials (TDs), consisting of exercises, will allow the concepts seen in class to be used.

Learning outcomes covered on the course

At the end of this course, students will be able:

- to understand elements of the theory of supervised learning;
- to understand the bias-complexity trade-off of an hypothesis class;
- to understand and use PAC bayesian bounds of supervised learning (in particular those of binary classification problem).

Description of the skills acquired at the end of the course

C1.2: Select, use and develop modelling scales, allowing for appropriate simplifying hypotheses to be formulated and applied towards tackling a problem;

3MD4150 – Natural language processing

Instructors : **Joël Legrand**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **40**
On-site hours (HPE) : **29,00**

Description

Natural language processing (NLP) is a field, at the crossroads of machine learning and linguistics, that allows to automatically exploit natural language text data using computer tools.
This course aims to introduce linguistic concepts, methods and tools for handling and exploiting large amounts of textual data.

Quarter number

SG11

Prerequisites (in terms of CS courses)

- Master the basic concepts of machine learning
- Students need to have a practical experience in at least one of the main deep learning libraries (Tensorflow, pytorch, torch, ...)

Syllabus

This course introduces the main linguistic theories used to model natural language (e.g. formal grammars, dependency grammars, etc.).
It presents the various natural language processing (NLP) tools available and the statistical models on which they are based.
Particular emphasis will be placed on the deep learning methods that constitute the state of the art for most NLP tasks.

Class components (lecture, labs, etc.)

Each session will include a lecture part during which new concepts will be introduced, followed by a practical work session.
Practical work sessions will be direct applications concepts seen in lectures.
All teaching materials will be provided to students.

Grading

Evaluation 1:
Type of exam: practical session exam
Learning outcomes assessed: Use of the linguistic notions and computer tools introduced during courses.
Modality: The examination will take place in the computer room and will include a theoretical part on classical NLP statistical models.
It will be followed by a practical part focussing on the tools and linguistic concepts used during the practical work sessions, applied to a real problem.
Percentage: 50%.

Evaluation 2:
Type of exam: project
Learning outcomes assessed: Use of the linguistic notions and computer tools introduced during the courses.
Demonstrate autonomy and creativity in dealing with a concrete problem.

Modality and return: The subject and the grade scale will be communicated in the middle of module. It will be based on data from the Kaggle platform providing challenges in data science, based on real industrial problems. The project will be returned by the end of the module.
A feedback on the work provided will be given at the same time as the grades.
Percentage: 50%.

Course support, bibliography

- Installation of the deep learning library PyTorch: https://pytorch.org/
- Reference book on deep learning (in english): https://www.deeplearningbook.org/
- NLP tools from the Stanford NLP team: https://nlp.stanford.edu/software/
- NLTK documentaton for python: https://www.nltk.org/

Resources

The lectures will be given by Joël Legrand and the practical work sessions by Joël Legrand and Jérémy Fix.
The theoretical concepts will be introduced during lectures and then applied during practical work sessions.
The practical work sessions will be mainly in python; the deep learning ones will be done using the PyTorch library (https://pytorch.org/).

Learning outcomes covered on the course

- To become familiar with the theoretical foundations for conceptualizing and modelling linguistic phenomena.
- Master the essential tools of TAL (lemmatizer, parser, etc.).
- Acquire autonomy for the automatic processing of textual content.

Description of the skills acquired at the end of the course

C1.4, Marker 2 : Design, detail and corroborate a whole or part of a complex system.
C3.6, Marker 1 : Evaluate the efficiency, feasibility and strength of the proposed solutions.
C8.1, Marker 3 : Work collaboratively in a team.

3MD4160 – Sparse models

Instructors : **Herve Frezza-Buet**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **20,00**

Description

The course introduces principles behind data transformation and optimization methods at the heart of automatic learning and data science, from the perspective of sparsity and robustness, applied to digital data compression (mp3, jpg) and representations by predictive models, making extensive use of algorithmic experimentation, intuition and history of science.

Quarter number

SG11

Prerequisites (in terms of CS courses)

This course requires a solid background in linear algebra and its use for the analysis of (quasi-) linear and time invariant systems (filter theory) via Fourier analysis (up to harmonic analysis), as well as good notions of empirical probabilities (statistical distributions, estimators). For practical work, knowledge of a digital scripting language (Matlab, Scilab, octave, Python, etc.) is required.

Syllabus

The course presents a travel through data analysis and learning, via different sparse tools and methods, aimed at explaining observations by a reduced number of parameters: data metrics, descriptors and transformations (norms, vector bases and frames, wavelets); implementation through data compression algorithms (audio, image, video, text); extension to prediction models (statistical moments, linear and polynomial regressions, parsimonious or robust models).

Class components (lecture, labs, etc.)

On each theme, students are first confronted with a "toy" problem for which they must mobilize their knowledge, ask themselves questions and implement first algorithms (in pairs). In a second step, after an exchange on this first phase, theoretical aspects, mathematical proofs and algorithmic tools are presented. Finally, in a third part, students apply these skills to a more complex problem.

Grading

The module will be evaluated by an oral examination in groups of two or three students, with a report provided in advance, on an integrative topic, designed to mobilize different skills and methods acquired during the course. If the number of students allows it, a project-type structure, allowing groups to collaborate, will be proposed.

Course support, bibliography

The course is accompanied by multimedia support in English, including bibliographic references, videos and links to technical/science social networks (such as StackOverflow/StackExchange)

Resources

Courses and practical work are given by Laurent Duval (ESIEE-Paris, Université Paris-Est Marne-la-Vallée and IFP Energies nouvelles). Courses and practical work are intertwined, using signals, images or experimental data ranging from simple simulations to real-world data.

Learning outcomes covered on the course

- To understand practical and theoretical motivations of optimization algorithms used in automatic learning and data science.
- To implement related algorithms in an adapted manner by understanding their meaning in relation to the problem at hand.
- To link different methods and implement them in a data processing flow.

Description of the skills acquired at the end of the course

C1.2, Marker 2 : Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem

C2.5 Master the skillset of a core profession within the engineering sciences (at junior level).

C3.6 Evaluate the efficiency, feasibility and strength of the solutions offered. / proposed solutions.

C3.7 Make pragmatic and informed choices with the aim of producing tangible results.

3MD4500 – Project MDS SDI - MTZ

Instructors : **Frederic Pennerath, Herve Frezza-Buet**
Department : **MENTION SCIENCES DES DONNÉES ET DE L'INFORMATION (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

The end-of-study project is an achievement allowing the knowledge seen during the year to be applied to an R&D oriented topic.

Quarter number

SD9 SG10 SG11

Prerequisites (in terms of CS courses)

The courses of the SDI/Metz program

Syllabus

The content strongly depends on the topic of the project.

Class components (lecture, labs, etc.)

It is a question of making progress during working meetings with supervisors and external partners when there are any, in order to deliver a deliverable containing the codes produced, well documented, a bibliographical study and the presentation of the work carried out.

Grading

The evaluation is done during a final oral presentation and on the basis of the examination of the deliverables. An intermediate presentation can be considered.

Resources

Students generally work in groups of 2 to 4, with a supervisor from CentraleSupélec or an external one.

Learning outcomes covered on the course

- Identify the type of method adapted to the specified problem.
- Achieve a relevant and well-presented state of the art
- Design and implement adapted and original solutions.

Description of the skills acquired at the end of the course

C3.5, Marker 1: Put forward new tools with either continual progress or disruptive solutions as the goal
C3.6, Marker 1: Evaluate the efficiency, feasibility and strength of the solutions offered. / proposed solutions.
C3.7, Marker 2: Make pragmatic and informed choices with the aim of producing tangible results.

3MD5010 – Stochastic Models in Finance

Instructors : **Ioane Muni Toke**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course introduces the foundations of continuous-time stochastic modeling in finance. Mathematical finance has been instrumental in the growth of financial markets for the past decades. Stochastic models are now benchmark tools for the pricing and hedging of financial products.

Both the mathematical study of the models and the implementation of associated numerical methods are proposed in this course.

Quarter number

SD9

Prerequisites (in terms of CS courses)

none

Syllabus

- Refresher in stochastic calculus (stochastic integral, Girsanov theorem)
- Black & Scholes model. Pricing with martingale measures. Pricing with PDEs.
- Lab/Project : Monte Carlo methods. Numerical schemes for PDEs.
- General stochastic financial models. Arbitrage theory. Feynman-Kac.
- Local volatility models. Stochastic volatility models.
- Lab/Project : SDE discretization and Monte Carlo methods for stochastic volatility models.

Class components (lecture, labs, etc.)

Lectures and tutorials (about 18h) and labs/project (about 6h in class, then personal work).

Grading

Final exam (50%). Lab/Project (50%)

Course support, bibliography

Jacod, Jean and Philip Protter (2003). Probability essentials. Springer.
Øksendal, Bernt (2013). Stochastic differential equations. 6th ed. Springer.
Lamberton, Damien and Bernard Lapeyre (1991). Introduction au calcul stochastique appliqué à la finance. Ellipses.
Shreve, Steven E. (June 2004). Stochastic Calculus for Finance II: Continuous-Time Models. Springer.
Bergomi, Lorenzo (2016). Stochastic volatility modeling. CRC Press.
Gatheral, Jim (2006). The Volatility Surface: A Practitioner's Guide. Wiley.

3MD5020 – Structuring and Asset Management

Instructors : **Yann MOYSAN, Thomas Chedru**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Capital Markets covers activities such as financing (banking, bonds, equities, securitization), investment (structured products, equity derivatives, fixed income, hybrids, asset management) and risk hedging (fixed income, foreign exchange, credit, equities) for a wide range of clients: Retail/Private Banking, Corporate, Financial Institutions (insurance, banks, pension funds, etc.).

The course objective is to provide applied and practical knowledge of Cross Asset Structured Products and the issues currently at the heart of trading rooms (Regulation, CVA, Risk management, ...). Delivered by financial engineering professionals, the course is interactive and focused on the practice of the structuring role on a daily basis.

Quarter number

SG10

Prerequisites (in terms of CS courses)

The course requires some basic knowledge of derivative pricing (Black&Sholes).
The Stochastic Models in Finance course is a prerequisite.

Syllabus

- Structured Products : presentation and design / "Classic" products and pricing and hedging issues
- Fixed Income and Inflation: Interest Rate Dynamics and Derivatives
- Fund Derivatives and Cushion Management
- Portfolio Management: Underlying Assets and Allocation Techniques
- “Innovative" underlyings and the pricing and management issues they raise
- Credit Risk: Products - Crisis / Regulation and Impacts on Derivatives
- Hybrids and Comodities

Class components (lecture, labs, etc.)

Courses and Practical Work (24h)

Grading

Written exam / QCM

Project: Design of a Structured Product / Asset Portfolio (Python)

Course support, bibliography

[1] Options, futures, and other derivatives - John C. Hull
[2] Finance de marché: Instruments de base, produits dérivés, portefeuilles et risques – Patrice Poncet / Roland Portrait
And many articles and publications to be discussed.

3MD5030 – Physics of Markets

Instructors : **Damien Challet**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This lecture focuses on the dynamics of financial markets from a mechanistic point of view. Its motivation is to provide a minimal modelling framework that is able to reproduce some well-known properties of asset prices. Investment strategies, learning and price dynamics are put forward as the most relevant ingredients of price dynamics and are studied with sophisticated agent-based models.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

1. Stylized facts of asset price dynamics
2. Trading strategies
3. Price predictability and learning
4. Unpredictable prices and unstable markets

Class components (lecture, labs, etc.)

CM: 12 hours
TP: 12 hours

Grading

50% assignments
50% final control

3MD5040 – Life insurance

Instructors : **Guillaume Metge, Youssef Saidi, Simon Colboc**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This class aim to introduce students to the life insurance and sparing market in France or Europa, as well as to the actuarial techniques used to model a life insurance portfolio (insured's behavior, demographics, finance).

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

Life insurance products & distribution
Calcul des engagements en assurance-vie, théorie de la ruine
Actuarial calculus, failure criterion theory
Valuation of a life insurance portfolio (Market Consistent Embedded Value*, deterministic vs. stochastic valuation, introduction to l'*Asset & Liabilities Management)
Mortality table and life expectancy (*Duration models, Kaplan-Meier estimator, Lee-Carter and derived models)*
Actuarial modelization of insured behavior (*focus on lapses : economic models, statistical models (GLM) & use of machine learning*)
Actuarial and financial international regulations (IFRS17, Solvency II)

Class components (lecture, labs, etc.)

Case study (50%) / Labs (50%)

Grading

Students will be guided into building a life insurance product. A presentation of this product, its modelization and actuarials KPI will be graded.

Course support, bibliography

Théorie et pratique de l'assurance vie, Fromenteau, Peteton
Modèles de durée - Applications Actuarielles, Planchet Thérond
Le rachat - Modélisations et préconisations, Adrien Suru
EIOPA Technical specifications

Description of the skills acquired at the end of the course

Knowledge of life insurance market
Life insurance tarification, profitability & risk measurement.

3MD5050 – Portfolio allocation

Instructors : **Christian Bongiorno, Romain Perchet**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course is designed to deepen portfolio optimisation. We explore beyond the foundations of Markowitz's classical portfolio theory by dealing with more advanced and robust methods of portfolio management. The course will highlight cases where traditional portfolio theory may be insufficient due to factors such as non-Gaussian returns and noise in the covariance matrices. Emphasis will be also placed on the practical and theoretical understanding of advanced portfolio construction techniques, including "robust optimization". A key component of this course includes hands-on lab sessions, where students will have the opportunity to apply these methods to real-world datasets.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None required, although students will benefit from a basic knowledge of Statistics, Optimization Problems, and Financial Concepts.

Syllabus

- Introduction to asset and portfolio management
- Portfolio construction and optimization methods
- Alternative strategic asset allocation methods to Markowitz
- Estimating variance and covariance matrix in high dimensions and covariance matrix filtering

Class components (lecture, labs, etc.)

10.5h Lab/Tutorials - 9h Lectures

Grading

50% Labs, 50% Project (oral defense) by team work

Resources

course and implementation

Learning outcomes covered on the course

Risk budgeting, Robust portfolio optimization, Asset allocation, Portfolio construction
Covariance matrix filtering, risk model, estimator of covariance matrix in large dimension

3MD5210 – Advanced Stochastic Models in Finance

Instructors : **Gaoyue Guo, Ioane Muni Toke**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course aims at introducing advanced stochastic models that allow to describe more precisely the financial phenomenon and to better meet the demands of practitioners. American option pricing and jump processes are presented, which contain both the associated methodology and applications in finance.

Quarter number

SG11

Prerequisites (in terms of CS courses)

CIP, calcul stochastique, EDP

Syllabus

1. Jump models: We introduce the Lévy process and its representation, and then the Poisson process. We focus on stochastic computing with jumps, and study the pricing and hedging of European options under some Lévy models.

2. Optimal stopping and dynamic programming: Motivated by its application in the pricing of American options, we consider optimal stopping problems. We first introduce its formulation, then the corresponding dynamic programming principle and the HJB equation (in continuous time).

3. Robust finance (optional): If time permits, we consider a framework that is fashionable and recently introduced. Robust finance does not start with an a priori model but rather with the information available in the markets. We study the trinomial model (uncertain volatility) and the martingale optimal transport problem.

Grading

Written control

Resources

5 lectures + 2 tutorials

Learning outcomes covered on the course

Students should be familiar with Black-Scholes model (continuous processes), Merton model, NIG model (jump processes) and know how to solve related problems, e.g. optimal stopping problem (American options) and hedging problem. In addition, students are required to have a complete understanding of the methodology (dynamic programming, Itô-Lévy decomposition, stochastic integration, etc.) and a mastery of the associated tools (Snell envelope, HJB equation, martingale representation theorem, Feynman-Kac formula, etc.).

3MD5220 – Fixed income

Instructors : **Faical Hihi, Ioane Muni Toke**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The objective of this course is to provide an overview of the interest rate products and their management models. In particular, the course aims to achieve the following objectives:
- Allow students to understand the link between the macroeconomic context and the formation of the yield curve.
- Present the main vanilla and exotic interest rate products with a focus on the economic factors justifying their use.
- Address the main valuation models for interest rate derivatives with a focus on product-model adequacy.
- Create awareness of issues related to model risk management. The course will address the main techniques used within investment banks to quantify and provision the potential losses linked to model risk.
The course is designed to take into account the main developments in the interest rate market in the recent years such as the CSA, multi-curve valuation, collateralization, negative rates, etc.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

- Formation of the rate curve: Definition of the concept of rates and their determining factors. Main rates (central banks rates, interbank, bond, swap, repo, etc.). Vanilla products: Money Markets, Future/FRA, Swap, Cap/Floor, swaptions.
- Valuation of Financial instruments: Reminder of stochastic calculus: In particular, Girsanov theorem and numeraire change techniques. Replication: review of the Black-Scholes PDE in the presence of collateral.
- Construction of the interest rate term structure: Bootstrapping technique. Multi-curve Framework/CSA.
- Valuation models
  - HJM and Hull White
  - Libor Market Model (BGM)
  - SABR
  - Hunt Kennedy
- Model Risk Management
  - P&L Explanation
  - Mapping technique: implied market distribution
  - Static replication: Carr Madan
  - Convexity Adjustment
  - Product-Model Adequacy
  - Quantification of model risk (Uncertain volatility, Barrier shift, Conservative approach, Alternative modeling, Other techniques).

Class components (lecture, labs, etc.)

Mainly lecture + project to be carried out outside class

Grading

Exam + Project

Course support, bibliography

Supports de cours : slides + notes de cours.

· ANDERSEN, L. & PITERBARG, V., Interest Rate Modeling, Atlantic Financial Press, 2010
· BRIGO, D. & MERCURIO, F., 2006, Interest- Rate Models: Theory and Practice - With Smile, Inflation and Credit (2nd ed.), Springer Finance.
· BURDA, M. & WYPLOSZ, C., Macroéconomie : Une perspective européenne, 6ème édition, De Boeck, 2012
· EL KAROUI, N, Couverture des risques dans les marchés financiers, Cours Ecole Polytechnique
· FRACHOT, A, Théorie et pratique des instruments financiers, Cours Ecole Polytechnique
· HAKALA, J., WYSTUP, U, 2002, Foreign Exchange Risk: Models, Instruments and Strategies, Riskbooks.
· HULL, J., 2012, Options, Futures, and Other Derivatives (8th Edition), Prentice Hall.
· HUNT, P.J. & KENNEDY, J.E., Financial Derivatives in Theory and Practice (rev. ed.), Wiley, 2004
· KERKHOF, J., Inflation Derivatives Explained : Markets, Products and Pricing, Lehman Brothers, 2005
· MARTELLINI, L., PRIAULET, P. & PRIAULET, S., 2003, Fixed-Income Securities: Valuation, Risk Management and Portfolio Strategies, Wiley.
· PATTERSON, B. & LYGNERUD, K., Détermination des taux d'intérêt, Parlement Européen, Direction Générale des Etudes, Série Affaires économiques, ECON-116 FR, 1999

Learning outcomes covered on the course

At the end of this course, students will be able to:
- Build a yield curve based on market data.
- Determine the criteria for choosing models and their calibration instruments based on the products.
- Conduct a critical analysis of the results obtained using a model.

3MD5230 – High-Frequency Data and Limit Order Books

Instructors : **Ioane Muni Toke**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course is intended for students interested in the empirical study, mathematical modelling and numerical simulation of modern, order-driven financial markets.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Stochastic calculus, Python

Syllabus

1 : High-frequency financial data and limit order books I.
    Lab: Stylized facts on trade data.
2 : High-frequency financial data and limit order books II.
    Lab: Stylized facts on quote data.
3 : Introduction to point processes I.
    Lab : Poisson processes.
4 : Introduction to point processes II.
    Lab : Hawkes processes.
5 : Hawkes processes in finance.
    Lab : Hawkes processes and high-frequency transaction data.
6 : Mathematical modeling of limit order books.
    Lab : Poisson LOB simulation.
7 : An introduction to market impact.
    Lab : Empirical market impact of LOB events.

Class components (lecture, labs, etc.)

Lectures (10h30), Python labs (10h30)

Grading

Labs (50%), final exam(50%)

Course support, bibliography

Abergel, Frédéric, Anane, Marouane, Chakraborti, Anirban, Jedidi, Aymen, & Muni Toke, Ioane (2016). Limit order books. Cambridge University Press.

Hasbrouck, J. (2007). Empirical market microstructure: The institutions, economics, and econometrics of securities trading. Oxford University Press.

And many research articles to be discussed in class.

Resources

Lectures + Labs

3MD5250 – Deep Learning in Finance

Instructors : **Damien Challet**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This lecture aims at exploring the promises and limits of deep learning in finance.

Promises: ability to exploit nonlinearities and hidden relationships, to solve problems out of reach of traditional computational methods, scenario generation.

The domains of application of this course include model calibration, timeseries generation, option pricing, classification, and prediction.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

1. Estimation
    1. single parameter
    2. model
2. Generation
    - univariate time series
    - multivariate time series
3. Prediction
    - volatility
    - price returns
4. Risk control
    - option pricing
    - portfolio optimization

Class components (lecture, labs, etc.)

CM: 12h, TP: 12h

Grading

100% TPs with individual oral examination

Course support, bibliography

- Estimation
    - single parameter https://arxiv.org/pdf/1812.05315

  - modèle https://arxiv.org/pdf/2007.03494.pdf
- Generation
  - Multivariate: https://ieeexplore.ieee.org/iel7/9040208/9052899/09053276.pdf
  - https://gmarti.gitlab.io/qfin/2020/02/03/sp500-sharpe-vs-corrmats.html
- Prediction / trading
  review: https://arxiv.org/pdf/2006.05515.pdf

- Risk control
  - Portfolio optimization: https://arxiv.org/pdf/2005.13665.pdf

Learning outcomes covered on the course

Understanding the abilities of artificial neural networks.
Choosing a suitable architecture for a given problem.
Implementing complex architectures.
Knowing how to help neural networks achieving the desired outcome.

3MD5260 – Portfolio Metrics

Instructors : **Nicolas Millot**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The aim of the course is to :
- Understand the difference between economic and theoretical values ;
- Understand the different components entering the price of a trade ;
- Learn about the trading floor organization in relation with those pricing components ;
- Understand the basics of quantitative risk-management and its relation to economic capital ;
- Understand how the 2008 crisis and new regulations have changed the derivatives landscape ;
- Learn about the role of quantitative analysts in this environment.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

Reminders about the fundamental theorem of asset pricing, Black-Scholes model
Default risk, CDS pricing, counterparty credit risk, derivations of unilateral CVA
Own credit risk, derivations of bilateral CVA
Default hedging and funding issues, CVA and FCA
Credit mitigation, netting and collateral, relations with close-out and funding, derivation of FVA, fully collateralized trades valuation
XVA implementation challenges, advanced topics in XVA, wrong-way risk modelling, ratings-based CVA and multi-currency funding
Impact of regulations on derivatives valuation, RWA, KVA, CLR charge, relations to QRM
Risk-measures, VaR, ES, modelling and implementation issues

Class components (lecture, labs, etc.)

Lectures (18h), TD (3h), TP (3h)

Grading

Labs (20%), written exam (80%)

Course support, bibliography

[1] Green, A. (2015). XVA : Credit, Funding and Capital Valuation Adjustments . Wiley.
[2] Embrechts, P., R. Frey, and A. McNeil (2005). Quantitative Risk Management : Concepts, Techniques, Tools. Princeton : Princeton University Press.
And many research articles to be discussed in class.

3MD5270 – Reassurance and extreme risks

Instructors : **Simon BLAQUIERE, Vincent MAAREK**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This « data science for reinsurance » course presents various concrete case of data science and statistical methods use on the reinsurance market. It covers both business aspects of reinsurance, theoretical approaches used to quantify extreme risks and reinsurance optimization of a reinsurance program. Several applications are proposed through case studies that focus on frequent reinsurance issues.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Programming skills in Python or R, statistics, probabilities

Syllabus

- Introduction to Reinsurance (reinsurance market, traditional reinsurance, origins, reinsurance methods and structures)
- Introduction to Alternative Reinsurance (origins of the ILS market, securitization, Cat Bonds, Collateralized Reinsurance, ILW, etc.)
- Atypical claims modelling (extreme values theory, distributions fitting, and applications to reinsurance pricing)
- Design and pricing of reinsurance programmes (choice fo the structure, cost of capital optimization, capital requirements, frequency x severity methods, wording)
- Natural catastrophes modelling (introduction to geospatial data, hazard, exposure, vulnerability and financial losses modules)
- Reinsurance per risk pricing (introduction to per risk/per event structures, MBBEFD methods, reinsurance profiles)

Class components (lecture, labs, etc.)

Lectures, exercises, Python and R labs to student's convenience

Grading

Project in Python or R to student's convenience

Course support, bibliography

Modeling Extremal Events for Insurance and Finance, Embrechts P, Kluppelberg K. and Mikosch T, Springer, 1997
Insurance Risk management and Reinsurance, G. Gorge, Lulu.com, 2016

ACT3251 Théorie du risque, H. Guérin, Université de Montréal (Notes de cours), 2012
Théorie des valeurs extrêmes, Thierry Roncalli, Note de cours de l'université Paris Dauphine, 2002
The Swiss Re Exposure Curves and the MBBEFD Distribution Class, S. Bernegger, Astin Bulletin Vol. 27, 1997
A guide to catastrophe modelling, RMS, The Review, 2008
About Catastrophe Models, AIR Worldwide, 2012
Catastrophes naturelles et réassurance, Swiss Re, 2003
Directive 2009/138/CE, Parlement européen et Conseil de l'Union européenne, Journal officiel de l'Union européenne, 2009

3MD5280 – Credit Risk : Quantification and Management

Instructors : **Olivier Toutain**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course is an introduction to Credit Risk as used in the world of Finance by Banks, Hedge Funds, Asset Managers, Fintechs and Rating Agencies. We will review together the description of credit risk, using real life examples, the measurement of default probability using different approaches of a single name or portfolio of corporations. The concept of Credit Risk will also be reviewed across the type of obligors, from sovereign issuer to households. Both Risk Management and Pricing concepts will be reviewed.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

1. Credit Risk Introduction
a. The old concept of debt
b. The financing of activities
c. Credit Risk Typology

2. Debts Instruments
a. From loans to CDS: characteristics and pricing
b. Credit Derivatives market
c. Counterparty Risk

3. Measuring Default Risk
a. Fundamental approach: Ratings
b. Scoring
c. Market-based information

4. Modelling of single exposure default risk:
a. Structural Models: Merton and its extension
b. Reduced-form models

5. Modelling of recovery risk and transition risk
a. Definition of those risk
b. Proposed models

6. Modelling of multi-names exposure (default correlation)
a. de Finetti as a way to encompass all approach
b. CreditMetrics
c. Copula generalization

Grading

Final exam composed of exercises and basics questions on the course

3MD6010 – Density functional theory

Instructors : **Erick Herbin, Pietro Cortona, Pauline Lafitte**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Density functional theory (DFT) is the most widely used method of performing electronic structure calculations for complex systems. This course will give to the students knowledge of the fundamentals of the theory as well as a critical understanding of the main approximations which are currently used.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Quantum Mechanics at the level of the first year CentraleSupélec course.

Syllabus

Complements of quantum mechanics

- Variational method, reminders and complements.
- Helium atom: ground state and first excited state. Singulet and triplet states.
- Angular momentum and its relation with rotations.
- Complex atoms: LS and jj coupling. Spin-orbit interaction.

Density functional theory

- Hohenberg and Kohn theorems.
- Kohn and Sham theory.
- V-representability problem and Levy theory.
- Local density approximation (LDA).
- Generalized-gradient approximations (GGA).
- Hybrid functionals.

Grading

Depending on how many students will attend the course. Very likely it will be a seminar.

Course support, bibliography

A good quantum mechanics book.
Parr and Yang, Density Functional Theory of Atoms and Molecules, Oxford University Press

Resources

Lectures

Learning outcomes covered on the course

Knowledge of the fundamentals of the density functional theory.
Knowledge of the various approximations in use, of their strengths and their failures.

Description of the skills acquired at the end of the course

Students will be able to perform electronic structure calculations with a full understanding of what the computer is really doing.

3MD6020 – Differential varieties

Instructors : **Pauline Lafitte, Philippe Bouafia**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Course support, bibliography

1) John Lee: Smooth Manifolds
2) Shigeyuki Morita: Geometry of Differential Forms.
3) Michael Spivak: Comprehensive Introduction to Differential Geometry

3MD6030 – Schramm-Loewner Evolution

Instructors : **Erick Herbin, Pauline Lafitte**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This is a course in a reading group - research group format, which sweeps through topics at the cutting edge of mathematics at the interface with theoretical physics.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Stochastic processes, Markov chains, Brownian motion

Class components (lecture, labs, etc.)

The course consists of two parts: after a few review sessions given by the Professor, the students present a theme in turn at the blackboard.

Grading

Student presentations and participation in sessions are graded.

Resources

Teaching team: Erick Herbin (CentraleSupélec), Grégory Schehr (LPTMS)

3MD6040 – Stochastic DEs and PDEs

Instructors : **Ludovic Goudenege, Pauline Lafitte, Erick Herbin**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

In this course, we will cover the fundamental notions necessary for the description of a stochastic partial differential equation,in particular the construction of Wiener processes and a stochastic integral in infinite dimension. This will allow us to prove the existence of solutions for partial differential equations with additive noise. An other chapter will deal with examples of numerical methods which allow to approach the solutions of these stochastic equations.
Examples of stochastic equations on various models (biology, heat, electrical circuits, finance, filtering) will be presented in each chapter to illustrate some of the behaviours of the solutions.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Notions of filtrations and martingales.
Basis in stochastic calculus.

Syllabus

1) Formulation of stochastic partial differential equations
Wiener process
Stochastic Integral
Existence of solutions, regularity and key theorems
2) Numerical Methods
Numerical schemes, convergence and numerical simulations

Class components (lecture, labs, etc.)

Lectures.

Grading

A 1,5hr partial exam and a 3hr final exam.

Course support, bibliography

[1] B. Øksendal, Stochastic Differential Equations : An Introduction with Applications.
Fifth Edition, Corrected Printing. Springer-Verlag Heidelberg New York. Springer-Verlag.
[2] E. Pardoux, Stochastic partial differential equations.
Lectures given in Fudan University, Shangai, 2007.
[3] G. Da Prato and J. Zabczyk, Stochastic Equations in Infinite Dimensions, volume 44.

Cambridge University Press, In Encyclopedia of Mathematics and Its Applications, 1992.
[4] D. Revuz and M. Yor, Continuous martingales and Brownian motion, volume 293 of Grundlehren der Mathematischen Wissenschaften [Fundamental Principles of Mathematical Sciences]. Springer-Verlag, Berlin, third edition, 1999.
[5] J.B. Walsh, An introduction to stochastic partial differential equations,
Ecole d'Eté de Probabilités de Saint-Flour XIV - 1984, 1986.

Resources

Teaching team: Ludovic Goudenège (CNRS)

Learning outcomes covered on the course

Knowledge of the classical theory of stochastic partial differential equations and their numerical simulations.

Description of the skills acquired at the end of the course

Manipulation of Itô-Wiener stochastic infinite-dimensional integrals.
Use of the stochastic convolution in particular for stochastic PDEs with additive noise.
Notion of convergence by compactness in probabilized spaces.
Generalization of Euler-Maruyama schemes for stochastic PDEs.

3MD6050 – Lie groups and algebras

Instructors : **Pauline Lafitte, Frederic Paulin, Erick Herbin**
Department : **MATHÉMATIQUES, MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The aim of this course is to give an introduction to the classical Lie groups (including SO(n), SU(n), SO(3,1)) and to the classification of their finite dimensional representations. We will discuss their appearances in particle physics (Standard Model gauge group, Quantum Chromodynamics gauge group, isospin symmetry of nucleons and pions, ...) and in special relativity.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Differential calculus, linear algebra

Syllabus

- Matrix Lie groups and algebras
- Finite dimension linear representations of Lie algebras
- Finite dimension linear representations of Lie groups
- The SU(2) and SO(3) groups, and isospin symmetry
- The Lorentz and Poincaré groups in special relativity
- The SU group (3) of flavour symmetry

Class components (lecture, labs, etc.)

Lectures.

Grading

Homeworks and a 3hr written exam.

Course support, bibliography

[1] E. Gourgoulhon. Relativité restreinte : Des particules à l’astrophysique. Savoirs actuels, EDP Sciences, 2010.
[2] Y. Kosmann-Schwarzbach. Groupes et symétries : Groupes finis, groupes et algèbres de Lie, représentations. Éditions de l’Ecole Polytechnique, 2006.
[3] F. Paulin, Introduction aux groupes de Lie pour la physique, Notes de cours.

Resources

Teaching team: Frédéric Paulin (Université Paris-Saclay)

Learning outcomes covered on the course

Classification of finite dimension representations of classical Lie groups and algebras

Description of the skills acquired at the end of the course

Application of Lie groups and algebras in particle physics and special relativity.

3MD6060 – Gauge Theory

Instructors : **Erick Herbin, Igor Kornev**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

3MD6070 – Quantum Field Theory - Math version

Instructors : **Erick Herbin, Herve Moutarde**
Department : **MENTION MODÉLISATION MATHÉMATIQUE ET MATHÉMATIQUES FINANCIÈRES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

PHYSICS AND NANOTECHNOLOGY MAJOR (PNT)

3PN1010 – Condensed Matter

Instructors : **Igor Kornev**
Department : **DOMINANTE - PHYSIQUE ET NANOTECHNOLOGIES**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

This course aims at providing an introduction to some basic concepts in condensed matter physics for undergraduate students in Engineering. No prior knowledge of condensed matter physics is required

Quarter number

SD9

Prerequisites (in terms of CS courses)

1SL3000 (Quantum and statistical physics)

Syllabus

- Periodic structure and symmetry of crystals
- Diffraction, reciprocal lattice
- Lattice dynamics
- Phonons
- Thermal properties
- Free electron gas
- Bloch theorem and band structure
- Nearly free electron approximation
- Tight binding method
- Magnetism
- Ferroelectricity
- Overview of superconductivity

Class components (lecture, labs, etc.)

Lectures + questions from students
Reading assignments (Kittel's book)
In class problem solving
Weekly homework assignments

Grading

Distribution of credits: Homework 40% (due in 7 days after it is assigned; 5 point off for each business day after deadline), Final exam 60%
Homework :
You have to show reasonable amount of work, instead of only showing the final results.
Specifically,

- Write neatly
- Show all intermediate steps
- Use lots of words and explanations, not only equations
- Always make sure that your answer makes physical sense

- Remember to staple the pages!

Important note: you can feel comfortable that you have truly mastered a problem if, and only if, you are able to explain it in detail.
Credit will be given only if the reader can easily follow the arguments.

Final Exam :
The final exam will be opened book, opened notes (with no access to the internet). Questions will come from readings, in-class exercises, homework assignments, lecture notes.

Course support, bibliography

The textbook for this class is: Kittel, Charles. Introduction to Solid State Physics. 8th ed. New York, NY: John Wiley & Sons, 2004. ISBN: 9780471415268.
A useful reference is: Ashcroft, Neil W., and N. David Mermin. Solid State Physics. New York, NY: Holt, Rinehart and Winston, 1976. ISBN: 9780030839931

Resources

Instructor: I. Kornev
The textbook for this class is: Kittel, Charles. Introduction to Solid State Physics. 8th ed. New York, NY: John Wiley & Sons, 2004. ISBN: 9780471415268.
A useful reference is: Ashcroft, Neil W., and N. David Mermin. Solid State Physics. New York, NY: Holt, Rinehart and Winston, 1976. ISBN: 9780030839931

Learning outcomes covered on the course

- Understand the relationships between the structure and the properties of materials;
- Demonstrate knowledge for crystal structures and characterization;
- Know simple physical models to describe the behavior of materials;
- Connect a macroscopic phenomenon to microscopic processes;
- Demonstrate an understanding of the lattice dynamics;
- Predict electrical and thermal properties of solids and explain their origin;
- Explain the concept of energy bands and effect of the same on electrical/optical properties;
- Understand the role of the lattice potential in the development of energy gaps;
- Describe the microscopic origins of the magnetic/ferroelectric properties of solids and explain some finite-temperature properties

Description of the skills acquired at the end of the course

Demonstrate an understanding of the basics of condensed matter physics;
Use the knowledge of condensed matter to predict and rationalize the structural, electronic, vibrational, and other physical properties of solids;
Develop problem solving skills on topics included in the syllabus

3PN1020 – Radiation-matter interaction

Instructors : **Jean-Michel Gillet**
Department : **DOMINANTE - PHYSIQUE ET NANOTECHNOLOGIES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

This course aims to provide a physical basis for the interaction between radiation and matter. In its first part, the course is limited to a semi-classical description by which we describe electromagnetic radiation using the tools of classical physics (Maxwell). At the same time, we make use of a quantum picture to represent matter.
It is in the second part that we describe the radiation+matter as a global system in its quantum representation. For that, we will thus need quantization of the electromagnetic radiation (the "second quantization"). We will then see the common points and those of differentiation between photon radiation and that carried by massive particles (neutrons most often).

Quarter number

SD9

Prerequisites (in terms of CS courses)

Quantum and statistical physics

Syllabus

Semi-classical interaction (part 1): Einstein coefficients
Two-level quantum systems: Rabi oscillations
Time-dependent perturbations: Fermi's Golden Rule
Semi-classical interaction (part 2): Lorentz model and oscillator strengths
Selection rules and modeling of Einstein coefficients
Classical scattering(part 1)
Classical scattering (part 2)
Scattering cross section: quantum approach for a massive particle (neutron)
Inelastic scattering: scattering of a neutron in the zero- or one-phonon regime
Photon-electron interaction potentials
Quantization of the electromagnetic field
Emission and absorption of photons (examples in spectroscopy)
Examination: construction of a course sequence

Class components (lecture, labs, etc.)

Lectures and tutorials. Interactivity is encouraged and participation is a component of the continuous assessment.

Grading

Final exam and continuous assessment.

Course support, bibliography

Application-driven quantum and statistical physics Vol 3 (World Scientific). Other bibliographic references will be given during the course.

Resources

Lectures and tutorials

Learning outcomes covered on the course

Modelling of Einstein coefficients (in support of the LASER description)
Identification of the mechanisms behind the properties of scattered radiation. Condition of absorption or emission of radiation.
Modelling of some spectroscopic phenomena.

Description of the skills acquired at the end of the course

Modelling of Einstein coefficients (in support of the LASER description)
Identification of the mechanisms behind the properties of scattered radiation. Condition of absorption or emission of radiation.
Modelling of some spectroscopic phenomena.

3PN1030 – Non-equilibrium statistical physics

Instructors : **Jean-Jacques Greffet**
Department : **DOMINANTE - PHYSIQUE ET NANOTECHNOLOGIES**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

The goal of the course is to provide an introduction to the basic concepts of nonequilibrium statistical physics. The first part of the course deals with non equilibrium systems. The second part deals with interacting particles. Several approaches to nonequilibrium systems will be introduced: linear response theory, langevin model, Boltzmann equation and irreversible thermodynamics. The role of inter particle interactions will be discussed and resulting collective phenomena such as phase transitions will be discussed.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Introduction to quantum mechanics
Introduction to equilibrium statistical physics

Syllabus

1. Linear Response Theory.
2. Fluctuation-Dissipation theorem.
3. Langevin model of Brownian motion. Application to noise modelling of linear systems.
4. Transport phenomena in gases. Boltzmann equation.
5. Introduction to irreversible thermodynamics
6. Mean-field approximation
7. Order parameter. symmetry breaking
8. Examples of phase transitions

Class components (lecture, labs, etc.)

Lectures
Problem solving classes
Homework

Grading

Homework
Written exam

Course support, bibliography

Cours polycopié:Introduction to nonequlibrium statistical physics, JJ Greffet

R. Balian, From microphysics to Macrophysics, Vol. 1 Springer Verlag, 1982
R. Balian, From microphysics to Macrophysics, Vol. 2 Springer Verlag, 1991
R Kubo,, M. Toda, N. Hashitsume, Statistical Physics II, Springer Verlag, 1985

Resources

Handout (110 pages)
Exercise texts
Homework text

Learning outcomes covered on the course

Link between fluctuations and linear response.
Using Fluctuation-dissipation theorem to compute noise spectra or linear response functions.
Extracting information on linear response from the noise spectrum.
Using Langevin model of fluctuations.
Using Boltzmann equation to study transport phenomena.
Phase transitions.

Description of the skills acquired at the end of the course

Basics of statistical physics.
Microcanonical, canonical and grand canonical ensembles.
Quantum statistics.
Linear response function, susceptibility and relaxation function.

3PN1040 – Numerical simulation and modeling

Instructors : **Hichem Dammak**
Department : **DOMINANTE - PHYSIQUE ET NANOTECHNOLOGIES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

Computer simulations are a necessary tool for research in physics. It is at the crossroad of experimental and theoretical approaches. The purpose of this course is to introduce the most common methods in simulation: molecular dynamics and Monte Carlo methods.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Quantum Physics
Statistical Physics
Mechanics of point particles
Fourier transform

Syllabus

- Modeling of interatomic interactions and introduction to the DFT method
- Configuration integral and generalized equipartition theorem.
- Monte Carlo Metropolis (MC) method Molecular Dynamics method and comparison with MC.
- Methods to derive microscopic and macroscopic properties: the heat capacity, the radial distribution function, the diffusion coefficient, the order parameters, the surface energy, the frequency dependence of the polarisability …

Examples of subjects proposed to students during supervised sessions: 1) Order-disorder transition. 2) The diffusion coefficient in argon. 3) The surface reconstruction and reordering. 4) Influence of cluster size on structural and optical properties. 5) The density of vibration states and dielectric constant in ferroelectrics. 6) Ferromagnetic et anti-ferromagnetic transition….

Class components (lecture, labs, etc.)

Four class sessions (12h):
C1) Molecular dynamics method and phenomenological interatomic potentials
C2) Monte Carlo Metropolis method
C3) Thermostats and inclusion of quantum effects in the DM method
C4) Introduction to the DFT method

Four TD sessions (12h):
Each pair of students chooses a project andworks on it during the tutorial sessions by carrying out the simulations necessary to achieve the objective. Depending on the students' backgrounds they will be asked to either (i) write a program or a subroutine, (ii) modify an existing program, or (iii) use an existing program to generate simulations and explain their results.

Grading

- A 10-minute quiz at the beginning of each lecture
- A 10-page report summarizing the work done during the TD sessions
- Oral presentation of project results.

Final grade: [(average of tests) + grade of the report and investment during the TDs + grade of the oral] /3

Course support, bibliography

Handout provided in French
Lecture notes (slides) in English and French
English book chapters

Resources

- Moulon Mésocentre (CentraleSupélec & ENS-Saclay)
- Teaching team:
Hichem Dammak (Cours en français et TD)
Igor Kornev (Cours et TD en Anglais)
Yann Chalopin (TD)
Gregory Geneste (TD)
Mehdi Ayouz (TD)
Fabien Brieuc (TD)
Pauline Richard (TD)
Nathalie Saouli (TD)

Learning outcomes covered on the course

We expect the students to choose and apply the suitable numerical method for solving a given physics problem. They should be able to analyze and discuss their obtained results.

Description of the skills acquired at the end of the course

- Selecting the appropriate interaction potential to describe the properties of a system according to the nature of the atomic bonds
- Applying Verlet's algorithm to solve equilibrium atom dynamics equations in the microcanonical ensemble
- Using the Metropolis Monte Carlo algorithm to determine the equilibrium configurations in the canonical ensemble

3PN1050 – FabLab prototyping

Instructors : **Pierre-Eymeric Janolin**
Department : **DOMINANTE - PHYSIQUE ET NANOTECHNOLOGIES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

This activity provides the students (in groups or individually) with an opportunity to design a prototype in the FabLab. This shall be an opportunity for the students to conceive and design a prototype to respond to a client's needs and requirements. The use of Arduino cards, 3D printing, laser cutting and so on will be made possible thanks to the FabLab as well as to the client's own resources.

Quarter number

SD9

Prerequisites (in terms of CS courses)

None

Syllabus

A series of projects will be presented to the students, who will have to form small groups tackling these projects. The following sessions shall be carried out through interactions with the teaching team, La Fabrique team and the client.

Class components (lecture, labs, etc.)

Work in small groups or individually

Grading

Presentation + demo of the device and questions.

Course support, bibliography

N/A

Resources

La Fabrique and client's institutions may provide some of the required means, once approved and properly trained when need be.

Learning outcomes covered on the course

Prototype Design, Project- and Client-based approach, familiarity with prototyping means.

3PN1060 – Issues and professions in physics engineering

Instructors : **Thomas Antoni**
Department : **DOMINANTE - PHYSIQUE ET NANOTECHNOLOGIES**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

The aim of these activities is to confront the issues and problems of contemporary physics in their social and economic context, as well as to present the professions that they generate. Offered at the beginning of the year, these activities allow students to concretize their professional project and to orient themselves in their search for an internship or a job. At the same time, they participate in the acquisition of knowledge in contemporary physics in a rather informal context. Essentially composed of seminars and visits, the program is constituted as the year goes by, according to the scientific or economic news, the students' wills and the partner companies' offers.

Quarter number

SD9

Prerequisites (in terms of CS courses)

None.

Syllabus

Site visits and seminars.

Class components (lecture, labs, etc.)

Site visits and seminars.

Grading

This activity is not graded but validated on attendance.

Resources

Site visits and seminars.

Learning outcomes covered on the course

A broad vision of scientific issues and careers in engineering physics in order to find your first job.

Description of the skills acquired at the end of the course

(C 1.6) Mobilize a broad scientific and technical base in the framework of a transdisciplinary approach.
(C 2.1) Have a thorough knowledge of a field or discipline related to the basic or engineering sciences. Transpose to other disciplinary fields, generalize knowledge. Identify and rapidly acquire new knowledge and skills needed in the relevant fields, whether technical, economic or other. To create knowledge, in a scientific approach.
(C 2.2) To master the skills of one of the basic engineering professions (at junior level).

3PN1510 – Seminars and careers in photonics

Instructors : **Marc Sciamanna**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS, ANGLAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **20**
On-site hours (HPE) : **10,00**

Description

The "Photonics and Nano-systems engineering" specialization trains engineers and masters in advanced information processing systems engineering, which will inevitably use the most advanced concepts in physics. In particular, technologies using light (photonics) and new physics at the nanometric scale make it possible to measure, communicate, secure and manipulate information while limiting our energy consumption and preserving our natural resources. This introduction will allow students to immerse themselves in this paradigm shift in information processing

Quarter number

SD9

Prerequisites (in terms of CS courses)

none

Class components (lecture, labs, etc.)

Lecture and visit to a research center

Grading

Written report following the introductory lecture and visit

Learning outcomes covered on the course

- to understand the challenges in information processing
- to define photonics
- to understand the evolution of physical properties when considering the nanometer scale

Description of the skills acquired at the end of the course

C1.5: Mobilize a broad scientific and technical base as part of a transdisciplinary approach.
C2.2. : Import knowledge from other fields or disciplines
C9.1. : Analyze and anticipate the possible consequences of one's choices and actions while respecting oneself, others and the environment

3PN1520 – Field and propagation

Instructors : **Delphine Wolfersberger**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS, ANGLAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **12,50**

Description

This course deals with the fundamentals of Electromagnetism. From the cohesion of matter to wireless telecommunications, the laws of physics that govern these phenomena are described by electromagnetism. First, this course covers the basic concepts in physics and mathematics necessary for the study of radiation, allowing the establishment of Maxwell's equations. The solution of these equations in the form of a plane wave will allow to discuss some fundamental properties of light. Secondly, the course addresses the notion of electromagnetic radiation and its applications in the field of free and guided propagation, with the concepts of antennas and the main characteristics of optical fibers. Thirdly, the course covers the basic concepts of laser physics and will deal with continuous and pulse lasers.

Quarter number

SD9

Prerequisites (in terms of CS courses)

None

Syllabus

Reminder of the physical and mathematical bases necessary for the study of radiation.
Electrostatics, magnetostatics, notions of field and vector potential, Gauss, Stokes or Ampere theorems
Maxwell's equations, solving Maxwell's equations
Basic properties of light
Free / guided propagation
Antennas: antenna technology, radiation pattern, gain and directivity, equivalent area
Characteristics of optical fibers: light guide, different types of fibers, digital aperture, dispersion, losses
Physics of lasers: 2/3/4 level structure, emission, coherence, polarization
From continuous laser to pulse laser

Class components (lecture, labs, etc.)

12h lectures
6h practical exercices

Grading

Written exam (duration: 2h)

Course support, bibliography

Electromagnétisme : Fondements et applications(Dunod 2020)
José-Philippe Pérez, Robert Carles, Robert Fleckinger

Resources

Pedagogical Team : Delphine Wolfersberger & Nicolas Marsal

Learning outcomes covered on the course

At the end of this module, students will be able to:
- Understand the physical and mathematical bases necessary for the study of radiation.
- Understand the principles of electrostatics and magnetostatics, such as the concepts of field and vector potential, Gaussian, Stokes or Ampere theorems
- Become familiar with Maxwell's equations and their resolution in plane wave form
- Learn the fundamental properties of light
- Understand the concepts of free / guided propagation and their applications (antennas, waveguides)
- Understand the main characteristics of optical fibers
- Understand the basics of laser physics.

Description of the skills acquired at the end of the course

C2.1: Have studied a field or a discipline relating to the fundamental sciences or the engineering sciences.
C2.3: Identify and quickly acquire new knowledge and skills required in relevant fields, whether technical, economic or otherwise.
C1.5: Mobilize a broad scientific and technical base as part of a transdisciplinary approach.

3PN1530 – Nanomaterials

Instructors : **Jean-Paul Salvestrini**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS, ANGLAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **20,00**

Description

Microelectronic circuits, colloquially referred to as microchips, combine billions of transistors on a small piece of semiconductor material. Their amazing integration densities have made today's information and communication society a reality. Microelectronics technology is permanently revolutionizing industry, industrial and consumer products.Microfabrication and nanofabrication are the basis of manufacturing for nearly all modern miniaturized systems that are ubiquitously used in our daily life. Examples include; computer chips and integrated sensors for monitoring our environment, cars, mobile phones, medical devices and more.This course gives an overview of the different techniques used for the fabrication, at the micro and nano scale, of these kinds of devices with a focus on photonic devices such as LEDs, VCSELs, Lasers,...

Quarter number

SD9

Prerequisites (in terms of CS courses)

Semiconductor physics
Laser physics

Syllabus

• Fundamentals of optical and electronic materials
• Device design
• Clean room description and organisation
• Bulk material growth techniques
• Technological processes for device fabrication and integration
- Semiconductor wafers
- Epitaxy and material deposition
- Lithography
- Etching
- Doping
• Examples of design and fabrication of optical devices
- LEDs
- PV cells
- VCSELs

Class components (lecture, labs, etc.)

• 9 lectures (9x1h30)
• 2 practice sessions (2x1h30)
• 1 lab tour of the Institut Lafayette (1x1h30)

Grading

• 1 final exam (2h)

Resources

• 9 lectures (9x1h30)
• 2 practice sessions (2x1h30)
• 1 lab tour of the Institut Lafayette (1x1h30)

Learning outcomes covered on the course

• Fondamentals of optical and electronic materials
• Device design
• Clean room description and organisation
• Material growth techniques
• Technological processes for device fabrication and integration
• Examples of design and fabrication of optical devices

Description of the skills acquired at the end of the course

The desired outcome is to provide the student with enough basic information so he/she can understand literature related to his/her desired topic and allow him/her to begin developing new technologies. In that frame, the student will know how to:

· Select the correct fabrication process for a specific micro-device or microsystem
· Establish the workflow for the cleanroom processes
· Resource planning for a given microsystem fabrication

3PN1540 – Numerical methods

Instructors : **Damien Rontani**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS, ANGLAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Numerical methods are an essential part of the toolbox engineers for the modelling and simulation of complex systems. Applied Physics and engineering sciences are one of scientifc domains where these methods are used extensively because because of the large variety of complex models encountered (integro differential equation, partial derivative, noise, nonlinearity,...).
This lecture will allow students toacquire the fundamental background in various numerical techniques to solve a large class of problems. The methods will be applied to physical complex systems with an emphasis on photonics devices.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Basics on physical modeling (ordinary differential equation and partial derivative equations)
Basics in Optimization
Programmation in Matlab, Python, or C/C++

Syllabus

Numerical simulation of ordinary and stochastic differential equations (1.5h)

- Numerical solving of ordinary differential equation (ODE): Runge-Kutta and predictor-corrector methods. Numerical solving of stochastic differential equation (SDE) with Euler-Maruyama, Milstein, and stochastic Heun algorithms.
- DM : Simulation of a laser diode with spontaneous emission noise.

Numerical simulation of systems of nonlinear partial derivative equations (PDE) (9h)

- General notions on PDEs and their applications. Presnetation of finite-difference method in time (FDTD) - Implicit and explicit algorithms.
- TD + DM : Analysis of a photorefractive system.
- Presentation of spectral methods for solving PDEs. Complements on PDEs (coupling)
- TD : Implementation of the *Beam Propagation Method*

Stochastic methods (3h)

- Basic notion on the generation of random numbers. Principles of Monte-Carlo methods. Variance Reduction. Monte-Carlo methods with Markov-Chains (MCMC). Métropolis-Hasting Algorithms
- TD + DM : Numerical Problems with Monte-Carlo methods.

Finite element methods (4.5h)

- Presentation about the finite element method (FEM). Galerkin Approach. Meshing techniques.
- TD + DM : Implementation of the FEM on a multiphysics problem using a commercial / academic software

Class components (lecture, labs, etc.)

Lectures with on focus on practical aspects related to algorithmics and their software implementation. Each concept presented during a lecture is also implemented numerically during small classes (TD) and/or homework (DM).

Grading

The grading policy relies on four delivrables associated with each section of the lecture (*i.e*. TD and/or DM), which will consists of (i) short reports presenting / interpreting the numerical results and (ii) simulation codes in appendix. Each delivrable will be graded over 20 pts and will have a specific due date. Any missing report will receive a null grade.

Final grade = weighted sample mean of the four delivrables.

Course support, bibliography

Teaching Material : Slides from CentraleSupélec (French and English)

Bibliography :

- W. H. Press, S. A. Teukolsky, W. T. Vetterling, B. P. Flannery, "Numerical Recipes : The Art of Scientific Computing", 3ème édition, Cambridge University Press (2007)
- Joe D. Hoffman, "Numerical Methods for Engineers and Scientists", 2nd Ed., Taylor & Francis (2001)
- J. Kiusalaas, "Numerical Methods in Engineering with Python 3", 3rd Ed., Cambridge University Press (2013)

Resources

Teaching Staff : Damien Rontani, Delphine Wolfersberger
License for Matlab and other commercial / academic software for numerical simulation
Students' personnal computer / laptop.

Learning outcomes covered on the course

By the end of this lecture, students will be able to implement numerical methods typically encountered in Applied Physics and Photonics using a maintream programmation language (ex. Python, Matlab or C/C++). For more advanced multiphysic simulations, they will be able to use basics functionalities of commercial / academic software.

Description of the skills acquired at the end of the course

C6.4: Solve problems through mastery of computational thinking skills

C7.1: Persuade at core value level; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. Highlight the added value

3PN1550 – Physics of information

Instructors : **Michel Barret**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **18,50**

Description

The dynamics of physical systems is usually modeled by a (i) deterministic set of equations describing accurate future temporal behaviors and (ii) a stochastic, unpredictable component. Analyzing and modeling the random signals generated by such dynamical systems allows defining and measuring physical invariants.
Information Theory can quantify the degrees of randomness in a physical system and predict its statistical properties despite the impossibility of predicting its accurate behavior. Exploiting this theoretical framework, it becomes possible to optimize such systems to achieve the best level of achievable performance in processing capability. One example is given by the digital communications systems currently forming the backbone of our modern telecommunication networks.
Moreover, novel paradigms based on the physical properties of multipartite quantum systems allow today to extend the classical notion of information theory with the perspective to develop new data-processing algorithms (number factorization, optimization) with no classical equivalent.

Quarter number

SD9

Prerequisites (in terms of CS courses)

- Probability 1A (CIP, 1SL1000),
- Signal processing ST4 (1CC4000)

It is advisable to have also followed:

- Statistics, Machine learning and Data processing ST4 (1CC5000),
- Digital environment, computer and programming SG1 (1CC1000).

Syllabus

- Stochastic processes (6h of course)
  1.1 Introduction (random signal, temporal distribution, moments, stationnarity, ergodicity)
  1.2 Power spectral density (Bochner and Wiener-Khinchin Theorems, spectral density, power spectral density)
  1.3 Estimation (introduction, Bayesian and non-Bayesian approach, régression, linear estimation)
  1.4 Spectral analysis (sampling and quantification of a digital signal, windowing effect, biased/unbiased estimators of the autocorrelation, periodogram and its extensions)
  1.5 Homework (CG): non-parametric spectral analysis.
- Information theory (6h of course)
  2.1 Introduction (digital communication, typical architectures)
  2.2 Entropy of a discrete memoryless source (information content, entropy of a discrete memoryless source, conditional entropy and mutual information, channel capacity)
  2.3 Entropy for continuous sources (extension of entropy to continuous source, Shannon Theorem : capacity for a continuous channel)
  2.4 Illustration of a continuous communication channel (définition, computation of error rate and performance of the ideal transmission chain)
  2.5 Homework (CG): simulation of transmission chain and evolution of the error rate as a fonction of the signal-to-noise ratio, estimation of entropy.
- Quantum Information (3h of course)
  3.1 Introduction (quantum states, measure and observables, density operator, tensor product)

3.2 Quantum Information theory (notion of qbits and physical implementation, multi-qbit systems, quantum entanglement, Neumann entropy, quantum decoherence, non-cloning theorem, quantum teleportation)
3.3 Quantum Computing: basic quantum circuits (CNOT, phase, and Hadamard gate). Illustration. Extension to application to quantum algorithms.
3.4 Homework (CG) : Short problems in quantum information.

Class components (lecture, labs, etc.)

16,5h of courses + 9h of tutorials + homeworks + quiz

Grading

Continuous grading (CG) : 3 homeworks (HW) with individual reports and a final written exam taken individually and consisting of multiple-choice questions (MCQ).

N1 = grade of the HW "Non-parametric spectral analysis";
N2 = grade of the HW "simulation of a transmission chain and evolution of the error rate as a fonction of the signal-to-noise ratio, estimation of entropy";

N3 = grade of the HW "Short problems in quantum information";

The CG grade is Ncg = (4*N1+4*N2+3*N3)/11;

The final grade is (65*Ncg + 35*Grade_MCQ)/100.

Unexcused absence during an individual evaluation gives a mark of 0. The second session of evaluation is an oral exam.

Course support, bibliography

M. Barret, Traitement statistique du signal, Eyrolles, 2009.

Resources

Teaching staff/ faculty: Damien Rontani, Jean-Louis Gutzwiller and Michel Barret
Some of the tutorials will be done with a computer (using Matlab or Python).

Learning outcomes covered on the course

By the end of the lecture, students will be able to analyze the performance of estimators of power spectral density (PSD) for stochastic processes and bridge these notions with key concepts from Information Theory (e.g. entropy) towards predicting the performance of digital communication architectures.

Description of the skills acquired at the end of the course

C1.2: Select, use and develop modelling scales, allowing for appropriate simplifying hypotheses to be formulated and applied towards tackling a problem;
C1.3: Apply problem-solving through approximation, simulation and experimentation;
C7.1: Persuade at the level of core values; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. To make the added value known.

3PN1560 – Experimental physics

Instructors : **Nicolas Marsal**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS, ANGLAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

The objective of this module is to develop experimental skills in the fields of electronics and photonics in order to better prepare the insertion of the students in their future industrial and research environments.

Quarter number

SG10, SG11

Prerequisites (in terms of CS courses)

Basic knowledges of electromagnetism, materials, optics.

Syllabus

Different laboratory works on:

Simulation and characterization of Semiconductor Components
Development of nano-components in a clean room
Gaussian beam optics

Class components (lecture, labs, etc.)

Practical works in the laboratory room

Grading

Report to be returned after each laboratory work. Average rating on the 3 reports.

Course support, bibliography

Photonic Devices, Jia Ming Liu

Fundamentals of Photonics, BAHAA E. & A. SALEH

Resources

Lecturers : Piotr Antonik, Jean Louis Gutzwiller, Nicolas Marsal, Thierry Aubert, Delphine Wolfersberger

Learning outcomes covered on the course

Understanding and knowing how to use different sources and characterization tools for applications in photonics.

Description of the skills acquired at the end of the course

Thanks to this experimental module, the students will learn the quantities and the physical tools allowing to characterize and analyze the light coming out from laser sources, to simulate and characterize semiconductor components and to discover the growth of materials in a clean room.
C1.1 Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem
C1.2 Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem
C1.3 Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation
C2.3 Identify and proceed independently with the new knowledge and skills required
C2.4 Produce data and develop knowledge using a scientific approach

3PN2010 – Nonlinear Photonics

Instructors : **Delphine Wolfersberger**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS, ANGLAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **14,50**

Description

This course deals with the physics of nonlinear photonics and is, for any engineer, an essential complement to any training related to optical telecommunications or optical information processing.
Nonlinear optical phenomena give the opportunity to produce more efficient, more compact, low power consumption devices providing functions such as frequency conversion or signal processing. The topics studied will concern both the foundations and the applications of photonic systems based on the nonlinear interaction of light - matter.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

Chapter 1: General - Introduction to Non-Linear Optics.
Chapter 2: Basic principles and formalism of Non-Linear Optics.
Chapter 3: Coupled wave equations and applications to the description of 2nd order processes: second harmonic generation, sum of frequencies, difference of frequencies, phase tuning, optical parametric oscillator.
Chapter 4: Intensity-dependent refractive index and applications to optical bistability, self-focusing of light, and phase conjugation
Chapter 5: Spontaneous and stimulated scattering of light: Rayleigh, Brillouin, Raman
Chapter 6: Photorefractive effect and application to the creation of photo-induced waveguides
Chapter 7: Non-linear dynamics of semiconductor lasers

Class components (lecture, labs, etc.)

18h00 Lectures

Grading

Individual oral examination

Course support, bibliography

Nonlinear Optics - R. Boyd (Thirs Edition 2008)

Resources

Pedagogical team : Delphine Wolfersberger & Marc Sciamanna

Learning outcomes covered on the course

Students will be able to:
Understand the physics and basic principles of Nonlinear Photonics
Use the formalism of Non-Linear Optics
Understand the coupled wave equations and their applications for the generation of 2nd harmonic, sum of frequencies, frequency differences, phase tuning, Optical parametric oscillator
Understand the applications linked to the index variation in an optical material (bistability, phase conjugation)
Understanding Raman scattering and its applications
Address more exploratory nonlinear photonic phenomena (autofocusing, optical routing, nonlinear dynamics of lasers).

Description of the skills acquired at the end of the course

C2.1: Have studied a field or a discipline relating to the fundamental sciences or the engineering sciences.
C2.3: Identify and quickly acquire new knowledge and skills required in relevant fields, whether technical, economic or otherwise.
C1.5: Mobilize a broad scientific and technical base as part of a transdisciplinary approach.

3PN2020 – Photonic components

Instructors : **Marc Sciamanna**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **ANGLAIS, FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **20,50**

Description

The "Photonic Components" course explains the physical principles and properties of the components that generate and amplify an optical signal. More particularly, the operation of a semiconductor laser, its static characteristics, its spectrum, its noise and modulation properties are described. Components like solid state optical amplifiers or fiber amplifiers are also presented in the context of optical telecommunications. The courses present both experimental observations and mathematical models of components.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

- Fundamentals of light amplification by stimulated emission
- Physical properties of a semiconductor laser : gain, phase-amplitude coupling
- Static properties of a semiconductor laser : threshold, longitudinal modes
- Dynamic properties of a semiconductor laser : relaxation oscillations, modulation bandwidth, chirp
- Noise properties of a semiconductor laser
- Optical feedback effects

Class components (lecture, labs, etc.)

Lectures and practical exercises

Grading

Oral exam

Course support, bibliography

« Semiconductor lasers », G. Agrawal and N.K. Dutta, Kluwers Academic Publishers (1993)

Learning outcomes covered on the course

- to understand the physical principle of laser and optical amplification
- to model a photonic component in the form of differential equations or partial derivatives
- to interpret the experimental measurements of spectrum, bandwidth and noise of a laser photonic component or amplifier
- to identify the choice of a component according to the envisaged application in photonics

Description of the skills acquired at the end of the course

C1.3: Apply problem-solving through approximation, simulation and experimentation
C2.1: Have studied a field or a discipline relating to the fundamental sciences or the engineering sciences
C2.3: Identify and quickly acquire new knowledge and skills required in relevant fields, whether technical, economic or otherwise
C7.1 : In substance: Structure your ideas and your argument, be synthetic (hypotheses, objectives, expected results, approach and value created)

3PN2030 – Optical information processing

Instructors : **Nicolas Marsal**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS, ANGLAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **20,00**

Description

The concepts of optical information processing are approached from the point of view of Fourier optics. Spatial filtering, optical correlation and holography are used as examples. The objective is to describe these techniques with the minimum of mathematics, emphasizing on the contrary the principles and physical phenomena. This discipline has always been perceived as rich in application prospects since we know that light calculates by propagating ...

Quarter number

SG10

Prerequisites (in terms of CS courses)

Basic knowledge of electromagnetism, materials, optics.

Syllabus

Fourier optics and image formation
Analog information processing
Analog and digital holography
All-optical control of information
Introduction to neuro-morphic calculus using light

Class components (lecture, labs, etc.)

Alternation between courses, TD, TP in the lab.
12h lectures and 6h practical exercices

Grading

Oral presentation at the end of the course on the basis of a group presentation of 2 to 3 students (the mark will be individual). 1.5h.

Course support, bibliography

Joseph W. Goodman,“Introduction to Fourier optics”, McGraw-Hill,1988, ISBN 0-07-023776-X
Paul Smigielski, “Holographie industrielle, Teknea, 1994, ISBN 2-87717-041-1
Thomas W. Cathey, “Optical information processing and holography”, John Wiley & sons, 1974, ISBN 0-471-14078-3

Resources

Lecturers : Jean Maufoy, Nicolas Marsal, Damien Rontani

Learning outcomes covered on the course

Thanks to this course, students will learn the quantities and the physical and mathematical tools which make it possible to understand and analyze light, treated here as a signal.
They will see targeted applications in optical information processing, including optical correlation, optical memories, light-based neuro-morphic computation.

Description of the skills acquired at the end of the course

C1.1 Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem
C1.2 Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem

C1.3 Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation
C7 Know how to convince

3PN2050 – Lab. Photonics 1

Instructors : **Delphine Wolfersberger**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **ANGLAIS, FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

This practical work is structured around 4 experiments that allow students to manipulate and understand the concepts covered:
- in the course of Optical information processing (holography)
- in the course of nonlinear photonics (electro-optical modulator)
- photonic components (laser emission)
- electromagnetism (guided propagation and information transmission in optical fibers)

Quarter number

SG10

Prerequisites (in terms of CS courses)

Lectures :
Optical Signal processing
Non Linear Photonics
Electromagnetisms

Syllabus

Exercise 1: Holography: The objective of this practical experiment is to produce a hologram in transmission (readable with a laser) then in reflection (readable in white light).
Exercise 2: Electro-optic modulator: To transmit information at high speed, it is necessary to use fast modulators (electro-optical): the objective of this experiment is to implement a transmission of sound in free space.
Exercise 3: Laser emission: the aim of this practical work is to manipulate and adjust a laser cavity to allow laser emission and then to characterize the beam generated in this cavity.
Exercise 4 : Transmission of information using optical fibers. For several decades, optical fiber has gradually replaced the electric cable in information transmission systems. It is now installed at home (FTTH Fiber To The Home).

Class components (lecture, labs, etc.)

Practical experiments 12h00

Grading

Report of the experimental manipulation for each subject

Resources

Optical experimental set-up and components
Pedagogical team : Nicolas Marsal & Delphine Wolfersberger & Marc Sciamanna & Yves Houzelle

Learning outcomes covered on the course

Students will be able to:
- To perform laser alignments in free space using specific optical equipments: mirrors, lenses, microscope objectives, separator cubes.
- To build an optical system to generate interference
-To characterize a laser source (waist, wavelength, Rayleigh zone).
- To handle optoelectronic components for telecommunication transmissions (laser sources, modulators, optical fibers, photodetectors)

Description of the skills acquired at the end of the course

C2.1 : Avoir approfondi un domaine ou une discipline relative aux sciences fondamentales ou aux sciences de l'ingénieur.
C1.5 : Mobiliser un large socle scientifique et technique dans le cadre d’une approche transdisciplinaire.

3PN2070 – Photonic computing

Instructors : **Damien Rontani**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS, ANGLAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **20**
On-site hours (HPE) : **12,50**

Description

Photonic computing is a field which has undergone a rapid development over the last ten years; it offers novel paradigms for information processing while exploiting advantageously the physical properties of optics (i.e. broad bandwidth, parallelism, low energy consumption...). This elective course will follow a seminary format around four main themes : (1) neuromorphic approaches, (2) intégration for realization of on-chip systems (Photonic on silicone, photonic cristals, optomécanical systems, nano-optics), (3) optimization by physical systems (ex. Coherent Ising machines, Quantum optics for solving complex problems) and (4) emergent technologies.

Prerequisites (in terms of CS courses)

Modeling (1CC3000)
Statistics and Machine Learning (1CC5000).
Digital Signal Processing (1CC4000)
Photonic Components (3PN2020)

Syllabus

Photonic neural networks (4 courses)

- General overview of artificial neural networks (ANN), supervised and unsupervised learning. Notion of Reservoir computing. Applications.
- Fibers systems
- Free-space systems of large dimension

Photonique Integration for computing (2 courses)

- ANN integration on silicon photonic platform. Building blocks (waveguide, delay lines, couplers). Use of micro-resonator.
- Photonic crystal cavities.

Photonic systems for optimization (1 course)

- Introduction to Ising Machines

Emergent approaches (1 course)

- Notion of Deep nets. Integrated photonic deep nets (e.g. diffractifve systems)
- Volumic integration

Class components (lecture, labs, etc.)

Plenary lectures with a colloquium format with a strong emphasis on practical aspects and illustrated with numerous examples from the latest technological developments. Some notions will be illustrated directly in the lab if time permitted.
Evaluation: one final exam

Grading

The evaluation will be a technical analysis / synthesis of a recent scientific article imposed by the teaching staff / faculty. This analysis will consist of the writing of an individual report of about 5-10 pages.

Course support, bibliography

Photonic Reservoir Computing : Optical Recurrent Neural Networks
Daniel Brunner, Miguel C. Soriano, and Guy Van der Sande
De Gruyter (2019)

Resources

Teaching staff / Faculty : Damien Rontani and Piotr Antonik
Experimental setups in the laboratory of the Metz Campus to illustrate some of the concepts seen in class

Learning outcomes covered on the course

The learning objectives for this class are the following ones :

- Understanding of the guiding principles for designing photonic neuro-inspired architecture
- Acquiring a global perspective on photonic computing including the various existing approaches and those currently under development

Description of the skills acquired at the end of the course

C.1.5 Bring together broad scientific and technical concepts in a core structure contained within the framework of an interdisciplinary approach
C7.1: Persuade at core value level; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. Highlight the added value

3PN2090 – Nonlinear science

Instructors : **Marc Sciamanna**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **ANGLAIS, FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **20**
On-site hours (HPE) : **14,00**

Description

Non-linear sciences concern both the description of non-linear phenomena and the development of mathematical tools allowing them to be modeled, explained and predicted. By non-linear phenomenon we mean the consequence of a non-linear relationship between the variables characterizing the state of a system. This non-linear phenomenon can modify the dynamics of a system but also its spatial organization.

Prerequisites (in terms of CS courses)

None

Syllabus

- history of nonlinear sciences

- chaos
- fractals
- bifurcations of stationary and periodic solutions
- synchronisation and networks of coupled oscillators
- modelling and numerical simulations

Class components (lecture, labs, etc.)

Lectures and practical exercises

Grading

Written exam

Course support, bibliography

Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering, S. H. Strogatz, Westview Press (2014)

Learning outcomes covered on the course

- to describe how non-linear sciences appear in the history of science

- to define chaos and its properties (fractal dimension, Lyapunov exponent, entropy)
- to define the synchronization of non-linear oscillators
- to model a non-linear physical system by partial differential equations
- to determine the bifurcations of a non-linear system- numerically simulate a non-linear system

Description of the skills acquired at the end of the course

C1.2: Select, use and develop modelling scales, allowing for appropriate simplifying hypotheses to be formulated and applied towards tackling a problem;
C1.3: Apply problem-solving through approximation, simulation and experimentation;
C7.1: Persuade at the level of core values; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so structure and problematise the ideas themselves. To make the added value known.

3PN2210 – Green Photonics

Instructors : **Marc Sciamanna**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **ANGLAIS, FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **14,00**

Description

The course "Green Photonics" describes how photonics allows the conversion of light into electrical energy and allows to appreciate the performance of this conversion according to the material chosen and the parameters influencing the solar yield.

Prerequisites (in terms of CS courses)

None

Syllabus

- Physics of the photovoltaic effect
- Materials for solar cells
- Sizing of a solar installation
- Applications to optical telecommunications

Class components (lecture, labs, etc.)

Lectures and exercices in classroom

Grading

Written exam

Learning outcomes covered on the course

- Understanding the physics of a photodiode
- Understand the photovoltaic effect
- Understand the material architecture of a solar cell
- Estimate the yield of a solar installation

Description of the skills acquired at the end of the course

C2.1: Have studied a field or a discipline relating to the fundamental sciences or the engineering sciences.
C2.3: Identify and quickly acquire new knowledge and skills required in relevant fields, whether technical, economic or otherwise.
C1.5: Mobilize a broad scientific and technical base as part of a transdisciplinary approach.

3PN2230 – Imaging of living systems

Instructors : **Marc Sciamanna, Ninel Kokanyan**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **ANGLAIS, FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **50**
On-site hours (HPE) : **32,50**

Description

Biophotonics is the study of optical processes in biological systems, both those that occur naturally and in bioengineered materials. A particularly important aspect of this field is imaging and sensing cells and tissue. This includes injecting fluorescent markers into a biological system to track cell dynamics and drug delivery.
The topics include the fundamentals of optics and photonics, the optical properties of biological tissues, light-tissue interactions, microscopy for visualizing tissue components, spectroscopy for optically analyzing the properties of tissue, and optical biomedical imaging. It also describes tools and techniques such as laser and LED optical sources, photodetectors, optical fibers, bioluminescent probes for labeling cells, optical-based biosensors, surface plasmon resonance, and lab-on-a-chip technologies. Among the applications are optical coherence tomography (OCT), optical imaging modalities, photodynamic therapy (PDT), photobiostimulation or low-level light therapy (LLLT), diverse microscopic and spectroscopic techniques, tissue characterization, laser tissue ablation, optical trapping, and optogenetics. Worked examples further explain the material and how it can be applied to practical designs, and the homework problems help test readers' understanding of the text.

Prerequisites (in terms of CS courses)

Quantum Physics 1A

Syllabus

1 Structures of Biological Cells and Tissues
- 1.1 Macromolecules
- 1.2 Biological Cells
- 1.3 Biological Tissues and Organs

2 Basic Principles of Light
- 2.1 Lightwave Characteristics
- 2.2 Polarization
- 2.3 Reflection and Refraction
- 2.4 Interference

3.Optical Fibers for Biophotonics Applications

4 Fundamentals of Light Sources.
- 4.1 Radiometry
- 4.2 Light-Emitting Diodes
- 4.3 Lasers for Biophotonics

5. Light-Tissue Interactions
- 5.1 Reflection and Refraction Applications
- 5.2 Absorption in Biological Tissues
- 5.3 Light-Tissue Interaction Mechanisms
- 5.4 Photobiomodulation
- 5.5 Photoablation
- 5.6 Plasma-Induced Photoablation

6. Optical Probes and Biosensors
- 6.1 Overview of Biosensors and Probes
- 6.2 Optical Fiber Probe Configurations
- 6.3 Optical Sensors
- 6.4 Biorecognition Optical Fiber Sensors
- 6.5 Sensors Based on Optical Fiber Movements
- 6.6 Microbending Fiber Sensors

6.7 Interferometric Sensors
6.8 Photonic Crystal Fiber Biosensors
7. Biophotonics Technology Applications
7.1 Optical Manipulation
7.2 Miniaturized Analyses Tools

Class components (lecture, labs, etc.)

Lectures, exercices, practical work

Grading

Practical work (25%), final exam (75%)

Resources

Teaching team : Ninel Kokanyan, Laurent Mugnier, Vincent Michau, Cyril Petit

Learning outcomes covered on the course

• Evaluate advantages and disadvantages of particular bio photonics technique to solve the problems at the interface of engineering and biology of living systems
• Formulate the role of photonics in biology and biomedicine
• Derive the main concepts involved in the interaction of optical radiation with living systems of biology
• Argue the main applications of biophotonics in particular in the area of imaging and diagnostics
• Solve numerical problems which illustrate the principles of phenomena such as luminescence, absorption and scattering

Description of the skills acquired at the end of the course

C2.1. : Learn more about a field of engineering sciences or a scientific discipline
C3.3. : Concretely implement innovative ideas and commit to decisions, evaluate solutions, move to industrialization to deliver tangible results

3PN2240 – Optical communications

Instructors : **Jean-Louis Gutzwiller**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **16,50**

Description

This course addresses the main themes involved in optical telecommunications.

- Physical principles, components and effects of limitations (losses, dispersion) of the BER and the bitrate

Syllabus

- Reminders: concepts of waveguiding, attenuation and dispersion in optical fibres
- Passive components: couplers, isolators, circulators, filters and WDM couplers
- Optical time-domain reflectometry for fault localization
- Electro-optic modulators
- Optical receivers: direct and coherent detections
- Dispersion management (effect of dispersion on the maximum bitrate)
- Optical budget (effect of attenuation on the BER)
- Wavelength division multiplexing (WDM)
- Electronic components: Laser and photodiodes
- Noise

Class components (lecture, labs, etc.)

15h of lecture/tutorials.
1h30 written exam.

Grading

Written exam lasting 1h30.
If the exam fails, a new session will be offered under the same conditions as the initial exam.

Resources

This course will be in the form of lectures and tutorials given by two professors:

- Jean-Louis Gutzwiller
- Marc Wuilpart

Learning outcomes covered on the course

At the end of this course, students will be able to understand the technical issues associated with the implementation of an optical communication system.

Description of the skills acquired at the end of the course

C1.1 : Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem
C2.2 : Transfer knowledge and methodology across multiple disciplinary fields

3PN2250 – Lab. Photonics 2

Instructors : **Ninel Kokanyan**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS, ANGLAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **30**
On-site hours (HPE) : **20,00**

Description

This practical work aims to teach students the essential notions of optical measurements by giving them the necessary tools to make the student autonomous on an optical setup.

Prerequisites (in terms of CS courses)

Basic knowledge in optics and quantum physics

Syllabus

1. Studies of the main components of the experimental bench:
    - the CCD detector
    - the laser source
    - filters (interferential, notch, edge)
2. Principles and applications of Raman spectroscopy
    - Installation of the optical setup
    - Application to the study of plastics
    - Application to the study of a crystal

Class components (lecture, labs, etc.)

Experimental team work with explanations to the students while leaving an important autonomy.

Grading

Written report.

Course support, bibliography

SIMON, Guilhem (dir.) (2020), *Spectroscopies vibrationnelles. Théorie, aspects pratiques et applications*, Editions des archives contemporaines, France
(https://eac.ac/books/9782813002556)

Resources

Optical experimental devices.

Learning outcomes covered on the course

Through this practical study students will be able:
- to make an optical assembly
- to manipulate different optical components (filters, spectrometer, lenses, polarizers, ...)
- to design a Raman sensor on table
- to perform Raman measurements on different types of samples
- identify different types of materials with the Raman technique

Description of the skills acquired at the end of the course

C1 Analyze, design and build complex systems with scientific, technological, human and economic components
C2 Develop in-depth skills in a scientific or sectoral field and a family of professions

3PN2260 – Optical measurement

Instructors : **Nicolas Marsal**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **ANGLAIS, FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **20**
On-site hours (HPE) : **9,50**

Description

The objective of this course is to introduce the recent developments in optical instrumentation for photonics to better prepare students to their future career.

Prerequisites (in terms of CS courses)

Basic knowledge of electromagnetism, materials and optics.

Syllabus

In particular, we will investigate for the characterisation of materials :
-Generation of ultra short pulses: Femtosecond Lasers (Laser Ti: Sapphire)
-Wavelength emission using a optical parametric oscillator (OPO)
-Measuring optical pulses using different autocorrelation methods
-Raman and FTIR (Fourier Transform Infrared Spectroscopy) spectrocscopy
-We will also investigate the Scanning Electronic Microscope (SEM) (1000000x magnification)

Class components (lecture, labs, etc.)

9h lectures and 3h practical exercices

Grading

Oral presentation at the end of the course on the basis of a group presentation of 2 to 3 students (the mark will be individual). 1.5h

Course support, bibliography

Photonic Devices, Jia Ming Liu

Resources

Lecturers : Nicolas Marsal, Ninel Kokanyan

Learning outcomes covered on the course

Understanding and knowing how to use different sources and characterization tools for applications in photonics.

Description of the skills acquired at the end of the course

C1.1 Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem
C1.2 Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions

when addressing a problem

C1.3 Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation
C2.3 Identify and proceed independently with the new knowledge and skills required
C2.4 Produce data and develop knowledge using a scientific approach

3PN2265 – Digital telecommunications and associated electronics

Instructors : **Yves Houzelle, Jean-Louis Gutzwiller**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **35**
On-site hours (HPE) : **23,00**

Description

For the past decade, French electronics has been investing in high value-added fields and cutting-edge sectors such as aeronautics, defense, medical, smart card payment, fiber optic telecommunications, etc., abandoning consumer products such as televisions and telephones.

In the field of digital telecommunications, electronic systems cover a vast field of use, with techniques ranging from analog electronics, with the amplifier as the basic function, to digital electronics that implement the "intelligent" part of the systems. Moreover, the frequency range extends over a very wide spectrum, from low frequency applications such as audio processing to high frequency applications such as radio communications and optical fiber transmissions.

The very different constraints related to these very varied themes impose different design tools adapted to each problem.

This course will allow students to acquire the concepts and tools used to design electronic systems used in telecommunications.

Syllabus

The different chapters covered will be the following:

Principle of transmitters and receivers
Propagation and associated imperfections
Attenuation and link budget
The amplification.
Characterization of devices by S-parameters.
Phase locked loops.
Noise in electronic circuits.
Noise and error rate
Concepts and tools will be presented through the implementation of applications such as fiber optic communications or pulse width modulation transmissions.
A simulation of a non-ideal transmission will be performed in Python language.

Class components (lecture, labs, etc.)

A total of 22h30 which includes lectures and tutorials which are divided into 6 lectures + 9 tutorials (sessions of 1h30)

Yves Houzelle : 6 lectures + 2 tutorials
Jean-Louis Gutzwiller : 7 tutorials

A final exam of 1h30.

Grading

The evaluation will take the form of an oral presentation and a report on the simulation of a non-ideal transmission.

Learning outcomes covered on the course

Understand the technical and scientific issues associated with the implementation of a communication system.
Know the concepts and tools of radio frequency electronics.

Know how to dimension electronic functions used in telecommunications.

Description of the skills acquired at the end of the course

C1 : Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2 : Acquire and develop broad skills in a scientific or academic field and applied professional areas

3PN2500 – Project PNT PSY

Instructors : **Marc Sciamanna**
Department : **MENTION PHOTONICS AND NANO-SYSTEMS ENGINEERING (METZ)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE METZ**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

The end-of-studies project has a dual educational objective: a) to allow the student to develop his/her skills in project management and in particular to identify deliverables and their temporal sequence, b) propose to the student to deepen his/her theoretical and / or experimental knowledge in a field of specialization in research or an industrial problem.

Quarter number

SD9, SG10, SG11

Prerequisites (in terms of CS courses)

None

Syllabus

The project is chosen from a set of research projects and / or industrial projects, often proposed in partnership with public or private research and development laboratories in France or in Europe.

Class components (lecture, labs, etc.)

- Supervision of the project by one or two teacher-researchers, sometimes with the contribution of researchers
- First project session devoted to handling the problem
- Regular points to be managed by the students. who have the role of project manager
- Restitution of the project in the form of a written report and oral presentation
- The deliverable is software, a results file, and / or an experimental setup

Grading

Oral presentation and examination of the written report before an internal jury at CentraleSupélec, including, in the case of a partnership project, the presence of one or more jury members external to CentraleSupélec.

Learning outcomes covered on the course

- Project management
- Writing of a report
- Oral presentation
- Modeling of complex systems
- Experience in the scientific and technical fields of PSY

Description of the skills acquired at the end of the course

C1.1. : Analyze: study a system in its entirety, the situation as a whole. Identify, formulate and analyze a system within the framework of a transdisciplinary approach with its scientific, economic, human dimensions, etc.

C2.2. : Import knowledge from other fields or disciplines
C3.2. : Propose alternatives, formulate ideas by integrating the necessary external expertise (technical, commercial, HR, financial, legal, etc.), integrate risks and uncertainty
C7.1. : Structure your ideas and your argument, be synthetic (hypotheses, objectives, expected results, approach and value created)
C8.4. : Work in project mode by implementing project management methods adapted to the situation

3PN3010 – Quantum optics

Instructors : **Bruno Palpant**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

This course is an introduction to quantum optics. It comprises two parts, one devoted to the physics of lasers, the other to selected themes of quantum photonics.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

1. **Introduction to lasers**
- Some reminders
- LASER: operating principle
- Laser oscillation
- Amplifying medium
- Cavity
- Laser beam properties
- Pulsed lasers: principle

2. Coherence and field quantization

- Spectral width of a quantum transition
  - Doppler broadening
  - Radiation broadening
  - Cavity filtering
- **Coherences**
  - Interferometric analysis of light
  - Previous example: the monochromatic wave, the light that did not exist
  - Loss of coherence
  - Second order correlation
- **Quantification of electromagnetic radiation**
  - Energy of the electromagnetic field
  - Field states
    - Number states
    - Coherent states

3. Visit to laboratory experiments

Class components (lecture, labs, etc.)

In-class lessons with projected or on-board support

Grading

Written examination 1:30

Course support, bibliography

Handout for the part Coherence and quantization of fields +

- Hichem Dammak : Physique des Ondes. polycopié du cursus ingénieur CentraleSupélec, 2022.
- Le laser (une introduction à), Nicolas Treps et Fabien Bretenaker, EDP Sciences
- Claude Fabre : Atomes et Lumière, Interaction Matière-Rayonnement.
- Mark Fox : Quantum Optics. Oxford University Press, 3rd édition, 2007.
- Gilbert Grynberg, Alain Aspect et Claude Fabre : Introduction aux lasers et à l'optique quantique. Ellipses, 3rd édition, 1997.
- Rodney Loudon : The Quantum Theory of Light. Oxford Science Publications, 3rd édition, 2000.
- Daniel Walls et Gerard Milburns : Quantum Optics. Springer, 3rd édition, 1994.

Learning outcomes covered on the course

At the end of this course, students will have acquired basic notions allowing them either to go further in this field by starting a research work, or to have a good scientific culture for academic developments in a related discipline or an applicative work based on quantum technologies.

3PN3020 – Semiconductors

Instructors : **Romaric Landfried**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

This lecture aims at understanding the macroscopic electrical properties of solids, and by extension the functioning of basic electronic components, from the microscopic properties of these constituents.
Starting from the theoretical description of crystals, then using statistical physics, we will study conduction in solids and more particularly in semiconductors. Finally, the PN junction, at the base of almost all simple electronic components, will be approached before studying some simple cases (bipolar transistor and/or MOSFET for example).

Quarter number

SG10

Prerequisites (in terms of CS courses)

Notion of solid state physics, know the basics of statistical physics, have some notions of quantum physics.

Syllabus

1. Recall of the crystal structure: cohesion in solids, crystallography (direct space, reciprocal space, Brillouin zone, etc...), X-ray diffraction, elaboration and crystal defects
2. Statistical physics: Reminders of thermodynamics, notion of microstate, statistical entropy, partition function, canonical set, grand canonical set, etc... Fermi-Dirac distribution, Bose-Einstein distribution.
3. Electrons in crystalline solids: Sommerfeld theory (dynamics of free electrons, simple model of conduction in metals), Bloch-Brillouin theory (dynamics of quasi-free electrons, simple model of conduction in metals and semiconductors)
4. Semiconductors: main characteristics at equilibrium (carrier density, intrinsic and extrinsic SC), out-of-equilibrium phenomena (electrical diffusion/drift currents, generation/recombination, continuity equations), the PN

Class components (lecture, labs, etc.)

course : 9 x 1h30 + 1h30 written exam

Grading

1h30 written exam

Course support, bibliography

C.KITTEL « Physique de l'état solide » (Dunod)

S.O. KASAP « Electronic Materials and Devices » (Mc Graw Hill)

N.W. ASHCROFT, N.D. MERMIN « Solid-State Physics » (Saunders College Publishing)

C. NGÔ, H. NGÔ « Physique statistique, introduction » (Dunod)

H. MATHIEU « Physique des Semiconducteurs et des Composants électroniques » (Masson)

M. GERL, J.-P. ISSI « Physique des Matériaux » (Presses Polytechniques et Universitaires Romandes)

G. FOURNET « Physique électronique des solides » (Eyrolles)

Resources

15 HPE (Courses + exams)

online exercises (personal time)

Learning outcomes covered on the course

At the end of this course, students will be able to :
Know the phenomena of conduction in solids,
To know the orders of quantities related to semiconductors and more generally to describe a semiconductor (model, accessible quantities, etc...).
To know perfectly how to describe the phenomena occurring in a PN junction,
To understand the link between the microscopic phenomena taking place there and to know how to modulate these quantities to obtain the functioning of a desired component.

3PN3040 – Experimentation of quantum systems

Instructors : **Mohammed Serhir**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This module is a project-based learning. Its signature is clearly experimental. It comes at the end of the S10 sequence to bring an applicative perspective to the lectures addressed in the theme that can be summarized by "quantum optics and electronics". This module is constructed according to a two-way approach: bottom-up and top-down to bring a welcome flexibility and encourage student initiative. The projects are led by a team of students and the deliverables are to be presented in a free format: recorded videos, demonstration, slides or appropriate staging. Students are encouraged to take advantage of the academic ecosystem of Paris-Saclay and use its research potentialities to enrich their experimental projects.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

The groups will be composed of pairs/threes. Each group will work for a total of 24 hours (8 x 3 hours) on the development of their experimental project. The organization, implementation and presentation of the project are the responsibility of the group. The students will be able to rely on the supervisors and the material infrastructure of the CentraleSupelec's Laboratories. Among the experimental projects that can be addressed are based on the following kits: 1-Quantum Cryptography kit, 2-Quantum Eraser kit, 3-Bomb Tester kit, 4-Michelson interferometer kit, 5-Laser diode controller kit.

To illustrate quantum cryptography, we can use the experimental setup using the ThorLabs Quantum Cryptography kit. This offers the possibility to: i) discover how information can be encrypted and sent using light polarization, ii) generate an encryption key that allows private communication, iii) supervise the process of encryption, transmission and decryption of a secret message.
The second kit "Quantum Eraser" aims at highlighting the principle quantum mechanics complementarity. Designed to illustrate the fundamental principles of quantum physics, this experiment clearly shows how nature is often counter-intuitive at the quantum scale.
The third one is "Bomb Tester Analogy Kit" that highlights the principle of "interaction-free quantum measurement". The fourth project is using the "Michelson interferometer kit", where one can, using a laser and LEDs, explore the phenomenon of interference and examine how the coherence length of different light sources affects the output of the interferometer. Using this kit, one can determine the refraction index of Plexiglas plates and the thermal expansion coefficient of an aluminum rod. Other experimental work is being defined. They cover a wide spectrum ranging from the characterization of laser sources to the spectral analysis of a photodiode output signals for the classification of different noise types.

We encourage students to propose topics related to their scientific sensitivity/project. They will be able to work with researchers from CentraleSupélec and the University of Paris-Saclay to deepen their reflections.

Class components (lecture, labs, etc.)

The implementation of the experimental projects is spread over 24 houres (8 x 3h)

Grading

Presentation or video, commented demonstration

Skill C.1 is assessed by proposing a consistent experimental set-up. The skill is validated if the physical concepts are clearly stated.

Skill C.7 is validated if the group manages to objectify its thinking by means of a clear experimental set-up and quantifiable indicators (measurement).

Course support, bibliography

- Material available in the School's laboratories.
- Possibility of collaboration with academic partners.
- Characteristics and component datasheet

Resources

Teaching team: teachers intervene according to their expertise
Related experimental kits
La Fabrique

Learning outcomes covered on the course

After the module "Experimental Projects in Quantum Systems" students will be able to :

- Dimension/specify an experimental system to study a physical phenomenon.
- Characterize/Manipulate components for a given experiment.
- Establish working hypotheses and deploy an experimental plan.
- Model and evaluate the limitations of proposed approaches.

Description of the skills acquired at the end of the course

C1.2: Know how to use a model presented in class in a relevant way.
C1.3: Solve the problem with a practice of approximation and experimentation
C1.4 : Specify and design an experimental model
C1.5 : Mobilize a broad scientific and technical base in the framework of a transdisciplinary approach
C7.1: Convince in substance. Be clear about objectives and expected results. Be rigorous about assumptions and approach. Structure your ideas and argumentation. Highlight the value created.

3PN3050 – Quantum technologies: communications, computing and sensing

Instructors : **Benoit VALIRON**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

The aim of this module is to present three main axes identified as both critical and promising by the European Commission in the context of the second quantum revolution. Currently in the process of emerging from the laboratories, the general public spin-offs are expected in 5-15 years. The lessons will be in the form of a case study starting from the physical concepts involved to lead to the dimensioning of a system to address a concrete issue.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None.

Syllabus

- Communication and cryptography
- Computer and computing
- Sensors

Class components (lecture, labs, etc.)

Case studies.

Grading

Different according to each of the case studies, they will be announced by the speakers during each of their first sessions.

Resources

Case studies.

Learning outcomes covered on the course

Knowledge of the main current quantum technologies and their applications, as well as the basics of research and development.

Description of the skills acquired at the end of the course

(C1.2) To identify, formulate and analyze a problem in its scientific, economic and human dimensions.
(C1.3) Use and develop appropriate models, choose the right scale of modeling and relevant simplifying assumptions to address the problem.
(C1.4) Solve the problem with a practice of approximation, simulation and experimentation.
(C1.5) Specify, design, realize and validate all or part of a complex system.
(C2.2) To master the skills of one of the engineer's basic professions (at the junior level).

3PN3060 – Smart and functional materials

Instructors : **Pierre-Eymeric Janolin**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

This course introduces the concept of functionality in a material based of the typical example of ferroelectric materials. We shall see how such functionality can be useful to current and future technologies, and what physical principles underlies their operation. In addition, we will show how the phenomelogical description adopted here can be applied to other functionalities such as ferromagnetism. At last, we will see strategies to design and use materials with multiple combined and coupled functionalities, which then become "multifunctional".

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

1) General introduction to functional materials: notion of order parameter, susceptibilities/response function, basics of Landau theory of phase transitions.
2) Actuating, fine positioning, sensing: piezoelectric, electrostrictive.
3) Nanomaterials for low consumption and advanced computing
4) Materials for energy: Photovoltaic Effect, electro-caloric materials for refrigeration, thermoelectric materials.

Class components (lecture, labs, etc.)

Lectures and Case studies.

Grading

Detailed article analysis and oral presentation.

Course support, bibliography

Lecture slides available.

Learning outcomes covered on the course

During this course, the student will acquire the basic fundamentals necessary to understand scientific articles about smart functional ferroic materials.

Description of the skills acquired at the end of the course

At the end of this course, students will: 1) understand the concept of a functional material and its application to typical technological examples; 2) know how to use physical models to design materials for technological use.

3PN3070 – Magnetism and superconductivity

Instructors : **Francois Ladieu, Pierre-Eymeric Janolin**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

The course is split between :

Superconductivity: Introduction to Supraconductivity : Experimental manifestations of Supraconductivity. Microscopic theory of Bardeen Cooper and Schrieffer. Conventional superconductors. Ceramics with a high critical temperature..

Magnetism: Quantum origin of magnetism, the various manifestations of magnetism (para-, dia-, ferro-magnetism) and their origin, magnetic interactions and couplings with other degrees of freedom.

Quarter number

SG11

Prerequisites (in terms of CS courses)

1st-year Quantum physics course, especially the parts about spins, NMR, the hydrogen atom and atomic orbitals. The students are strongly encouraged to review these concepts and do again the corresponding exercices in order to refresh their memory.

Syllabus

Superconductivity:

1) History of discoveries in Supraconductivity and main practical applications.
2) Characteristic properties of a superconductor
3) Bose Condensation and Supraconductivity
4) London Equations, Flux Quantification, Josephson Effect, Squid
5) Bardeen Cooper Schrieffer microscopic theory
6) Type I and Type II superconductors
7) High temperature superconducting cuprates

Magnetism:

1- Why learning about magnetism : market, need for innovation, types of magnetic materials and applications
2- What are the magnetic elements and why ?
3- From isolated atoms to compounds
4- Itinerant magnetism
5- Coupling interactions: origin of magnetic orders
6- Couplings

Class components (lecture, labs, etc.)

Superconductivity: lectures

Magnetism: lectures, autonomous homeworks

Grading

Presentation based on scientific articles after having met with one of the authors;

Course support, bibliography

Magnetism:
"Magnétism I : Fundamentals", Etienne du Trémolet de Lacheisserie, laboratoire Louis Néel, Grenoble, Grenoble Université Sciences collection: especially chapter 7
"Simple models in magnetism": Ralph Skomski, Oxford Graduate Texts
These books are available at CentraleSupelec library

Resources

Superconductivity: Course handout, copy of the slides, references.

Magnetism: copy of the slides, references

Learning outcomes covered on the course

Superconductivity: Understanding the intrinsically quantum nature of superconductivity. Attractive coupling between electrons via virtual phonons. Practical and industrial use of superconductors. Breaking gauge invariance.

Magnetism: understanding of the mechanisms presiding over the existence of magnetic properties and their interaction with other properties. Ability to understand the underlying mechanisms of magnetic behaviors.

3PN3080 – Light and heat at low scale

Instructors : **Thomas Antoni**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

What is the behavior of light below its wavelength? What is heat at the scale of a molecule? What is the influence of their quantum nature? This course provides to students basic knowledge of the physics of heat and light at the lowest scales currently available. Indeed, at such dimensions they reveal rich properties of light and heat. with high technological potential. The fundamental aspects will be exposed and placed in application perspectives.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None.

Syllabus

Heat :
- Fluctuations and dissipation in condensed matter
- Conduction: phonons and thermal transport
- Heat radiation: from macro to nano
- Brownian relaxation in liquids
- Disorderd systems

Light:
1. Introduction & reminders
1.1 Reminders
1.2. Algebraic approach of electromagnetism
1.3 Mirrors smaller than the wavelength (case study)

2. Photonic crystals
2.1. Position of the problem
2.2. Shape of the modes
2.4. Filtering a laser for the detection of pollutants (case study)
2.5. Field measurement in a cavity (illustration)

3. Surface Polaritons
3.1. A little background
3.2 Permittivity models
3.3. Solutions of Maxwell's equations
3.4. Detectivity of a quantum well camera (TD)
3.5. Measurement of the dispersion relation of a surface wave (case study)

4. Optomechanics
4.1 Radiation pressure
4.2 Quantum regime observation
4.3 Optical cooling
4.4 Standard quantum limit

Class components (lecture, labs, etc.)

Lectures.

Grading

Written exam.

Course support, bibliography

Light part:

- Handout
- John D. Joannopoulos, Steven G. Johnson, Joshua N. Winn et Robert D. Meade : Photonic Crystals: Molding the Flow of Light. Princeton University Press, 2nd édition, 2008.

Resources

Lectures.

Learning outcomes covered on the course

At the end of this course, students will have an overview of the issues, phenomena, methods and applications related to these fields, and will be able to transfer the knowledge acquired to other aspects not covered during the course.

Description of the skills acquired at the end of the course

(C1.1) Study a problem as a whole, the situation as a whole.
(C1.2) To identify, formulate and analyze a problem in its scientific, economic and human dimensions.
(C1.3) Use and develop appropriate models, choose the right scale of modeling and relevant simplifying assumptions to address the problem.
(C1.4) Solve the problem with a practice of approximation, simulation and experimentation.
(C1.6) Mobilize a broad scientific and technical base in the framework of a transdisciplinary approach.
(C2.1) To have deepened a field or a discipline related to the basic or engineering sciences, to have transposed to other disciplinary fields, to generalize knowledge.
Identify and rapidly acquire new knowledge and skills needed in relevant fields, whether technical, economic or other. To create knowledge, in a scientific approach.
(C7.1) Convince in substance. Be clear about objectives and expected results. Be rigorous about the hypotheses and the approach. Structure ideas and argumentation. Highlight the value created.

3PN3110 – Non-equilibrium media, plasmas

Instructors : **Marie-Yvonne Perrin, Christophe Laux**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

This course provides the fundamental notions to understand plasmas and non-equilibrium media which intervene in numerous technological applications (ITER fusion demonstrator, plasma-assisted combustion, aerodynamic flow control, atmospheric re-entry, ...), but also natural ones since plasmas represent more than 99% of the visible matter

Quarter number

SG11

Prerequisites (in terms of CS courses)

Quantum and Statistical Physics (recommended)

Syllabus

- Introduction to plasmas: collisional and radiative phenomena, characteristic parameters of plasmas
- Introduction to fusion plasmas
- Physics of plasma flows: Boltzmann equation, general and species-specific fluid equations, transport properties (ambipolar diffusion, electrical conductivity,...)
- Physics of plasma discharges (Townsend discharge, glow discharge, arc, streamers) and industrial applications of cold plasmas.
- Atmospheric re-entry plasmas

Class components (lecture, labs, etc.)

The course is divided into equal parts of theoretical lectures and application classes. The application classes use the course concepts to explain or model practical applications of plasmas. For example, the fluid and kinetic models are directly used to understand and predict the phenomenon of ionic wind phenomenon which is used today in air purifiers, and which is currently studied in laboratories worldwide to reduce aircraft drag. As another example, the course on atmospheric reentry plasmas is directly implemented to predict radiative fluxes on space vehicles.

Grading

1.5-hour written exam

Course support, bibliography

- Slides of classes
- Partially Ionized Gases, M. Mitchner, Charles H. Kruger Jr.,Wiley series in plasma physics, 1992
- Principles of Plasma Discharges and Materials Processing, M.A. Lieberman and A.J. Lichtenberg, John Wiley and Sons, New York, 1994

Resources

Lectures (50%), TD (40%) and visit (10%) of plasma experiments at the EM2C laboratory (CNRS, CentraleSupelec)

Learning outcomes covered on the course

- Physical phenomena in plasma discharges
- Fluid description equations of plasmas: typically species conservation, momentum and energy equations for each species and for the global fluid
- Reactive phenomena in plasmas - reaction kinetics: application to the generation of superionized air plasmas and to plasma-assisted combustion, CO_2 conversion, and green H_2 production.
- Plasma radiation

Description of the skills acquired at the end of the course

At the end of this course, students will have understood the fundamental phenomena in plasmas as well as the physics of the discharges that produce most of the plasmas used in industrial applications. They will have had a broad overview of the industrial challenges of plasmas in the fields of energy, aerospace and materials processing.
Students will have had several opportunities to manipulate the fundamental concepts to analyze and explain typical plasma phenomena illustrative of industrial applications.

3PN3120 – From stars to planets

Instructors : **Éric Pantin, Sacha Brun**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

Part I: Stellar Physics and Star-Planet Interactions (12 h)
matter and radiation, thermodynamics, magneto-hydrodynamics, turbulence, helio/asteroseismology) and a large range of physical phenomena.
Responsible of the course : Dr. A.S. Brun
Lecturers : Dr. A.S. Brun, Dr. R. Garcia, Dr. A. Strugarek
Course Contents:
Why do stars shine? What is their destiny? Have they always existed? What is the origin of their magnetism and intense surface activity?
This course will focus on stellar evolution from birth to death of stars, with particular emphasis on the nonlinear dynamics operating within
them and on their surfaces, their interaction with their surrounding (exo)planets, touching on the concepts of space weather and habitability.
We will address the theoretical aspects of these questions but also those related to observations, starting from the basic physical concepts
and illustrating them with the latest advances (theoretical and observational) in the field. One of the particularities of this course is to mix
many physics topics (nuclear physics, turbulence, gravitation, magneto-hydrodynamics, dynamo effect, star-planet interaction).
The Sun will also serve as reference star, allowing us to distinguish what is specific to it from what is generic to these celestial objects.

Part II: From the formation of stars to that of planets (12 h)
Referent : Dr. E. Pantin
Stars formation in dense clouds. Planets formation : protoplanetary disks, solid matter growth from sub-micronic grains to planets. Presentation of
our own solar system as a typical case of planetary formation. Basics of exo-biology : are we alone in the universe ? What do exoplanets observations
tell us about the formation of our solar system ?

Quarter number

SG11

Prerequisites (in terms of CS courses)

Fair knowledge in basic physics, all fields

Syllabus

Part I:
1. Introduction to what a star is: cohesion and stability of a star, 1D model of stellar structure, energy balance, mass limits and degenerate stars (white dwarf, neutron star).
2. Convective turbulence and rotation in stars, dynamo effect and variability of the magnetic field of stars, seismology of the Sun and stars.
3. Structuring of the environment of stars -the asterosphere-, interaction and joint secular evolution of a star and its environment, space weather, habitability.

Part II:
- our solar system : presentation/family portrait
- stars formation by collapse in dense clouds. Young stars evolution
- formation of protoplanetary disks and evolution
- planets formation in protoplanetary disks and evolution
- exoplanets : detection and characteristics
- basics of exobiology : conditions for the emergence of life

Class components (lecture, labs, etc.)

Lectures and individual work

Grading

* Exam :
- MCQ for the stellar physics and star planet interaction Part I
- Questions to elaborate on ("planets formation") Part II

* Evaluation of personal homework (for "planets formation" part only)

Course support, bibliography

- lecture slides
- movies, animations, numerical simulations
- links to general public outreach recent results from observations and modeling
- review articles

Resources

Lecture with slides.

and for Part I: one lecture pdf file with main concepts.

Learning outcomes covered on the course

Part I: Understanding of stellar structure, dynamics and evolution. Basics of Space Weather and seismology of stars
Use and master various physics concepts, manipulate orders of magnitude with ease, describe the cycle of stellar matter, the fundamental building block of the universe.
Students will also learn to develop simple calculations in stellar fluids and plasmas mechanics.

Part II : How do stars form ? Why is there a relatively important fraction of stars with planets ? How planets form ? What are the conditions for the emergence of life ?
This lecture, based on basic principles of physics, will allow the students to tackle very diverse physics phenomena leading to the formation of planets,
the goal being a good understanding of the various physical processes at work.

Description of the skills acquired at the end of the course

Part I: Basics of stellar physics, stellar fluid and plasma dynamics, stellar magnetism, Space Weather, seismology of stars

Part II: Notions about the physics of stars and planets formation, exobiology

3PN3130 – Particles and cosmology

Instructors : **Vanina Ruhlmann-Kleider, Christophe Yèche, Laurent Chevalier**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

Particle physics describes the interactions between elementary particles, and its mathematical framework is a quantum field theory. The objective of this course will be to go through all the concepts and mathematical tools that lead to the construction of the standard model of particle physics. This model combines three of the four fundamental interactions: electromagnetic, weak, and strong. We will discuss the successes and limitations of this model, which has never been challenged, more precisely through the observation of the Higgs boson at CERN.
Cosmology is the counterpart of particle physics on the side of the infinitely large. The two fields are in interaction. The mysterious dark matter, the dominant component of the matter of the Universe, could well be constituted of an elementary particle not yet discovered. Conversely, the mass of neutrinos, which particle physics experiments are struggling to measure, could be measured through cosmological surveys. Cosmology aims to understand the Universe globally, in particular, to determine its content and its evolution. This is a field where spectacular progress has been made in the last twenty years, leading to a standard model of cosmology with its dark matter and dark energy components.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Particle physics
1. Brief history of the universe
2. Reminder of special relativity and dynamics
3. Mathematical tools: group theory, symmetries, lagrangians
4. From theory to measurement and experimental tests of particle physics MS
Cosmology
1. Introduction, an overview of cosmology
2. Geometry and expansion of the homogeneous Universe, Friedmann equation
3. Thermal history of the Universe
4. The inhomogeneous Universe: the formation of structures and the cosmic microwave background

Class components (lecture, labs, etc.)

Lecture courses

Grading

continuous monitoring:
lesson questions after each presentation, answer by e-mail sent before the next presentation
final test:
20 minutes presentation with some slides, on the understanding of a physics article

Course support, bibliography

Particle Physics

- Quarks and Leptons: An Introductory Course in Modern Particle Physics, Francis Halzen, Alan D. Martin
- An introduction To Quantum Field Theory, Peskin, Schroesder
- The Quantum Theory of Fields Volume I, S. Weinberg

Cosmology

- J. Rich, Fundamentals of cosmology, Springer, 2010
- S. Serjeant, Observational Cosmology, Cambridge University Press, 2010
- S. Dodelson, Modern Cosmology, Academic Press, 2003
- J. A. Peacock, Cosmological Physics, Cambridge University Press, 1998.

General Relativity

- J.B. Hartle, Gravity, Addison Wesley, 2003
- T.A. Moore, A General Relativity workbook, University science books, 2013

Resources

The slides presented during the lectures will be provided

Learning outcomes covered on the course

Overviews of particle physics and cosmology.
For the particles physic: we will approach the fundamental role of symmetries in the construction of the theory as well as the mathematical tools essentials to its construction

Description of the skills acquired at the end of the course

1. C1.2 - milestone 1 Know how to use a model presented in the lecture in a relevant way
2. C1.3 - Milestone 1B Solve a problem with approximation practice

3PN3140 – Quantum field theory

Instructors : **Igor Kornev**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

Quantum Field Theory (QFT) is the language describing physical systems with infinitely many degrees of freedom. It has numerous applications in particle, statistical or condensed matter physics. Its achievements are impressive, with Quantum Electrodynamics (QED) being presumably the most accurate existing theory. It is the conceptual framework of the Standard Model of particle physics, which successfully describes all known phenomena related to the electromagnetic, weak and strong interactions.
Born during the first half of the 20th century, QFT reached modern physical understanding only near the end of the 1970s. It can be seen as an algorithm providing testable predictions with systematically improvable accuracy. However the formal description of this algorithm does not meet yet the standard of mathematical rigor. Important physical questions have also been left unanswered so far, like the reasons for the short range of the strong interaction, or the confinement of quarks inside protons and neutrons. The CLAY Mathematical Institute identified the quest for a detailed understanding of QFT as one of the 7 key problems that should drive mathematical research during the 21st century. Solving this problem requires new mathematical and physical ideas.
The course introduces the basic type of fields playing an important role in particle and nuclear physics: scalar, spinor, and vector, and discusses their quantization. Relativistic invariance and gauge symmetry are treated in the Lagrangian framework. A perturbative approach dealing with interacting fields is developed, and the role of Feynman diagram is explained. The path integral formalism is introduced. The course ends with the computation of certain scattering processes involving electrons, positrons and photons in QED.
Refs. Halzen-Martin, Sakurai and Griffiths are useful introductory readings. Refs. Bell, Rivers, Mandl-Shaw, Peskin-Schroeder and Ryder contain the material that will be covered in the course. Refs. Jaffe-Witten, Douglas and Witten are advanced texts which give an idea of the mathematical complexity underlying QFT; this course is a prerequisite to understand them. Refs. Wilczek and Delamotte offer a perspective on advanced notions of QFT and their relevance to Nature.

Quarter number

SG11

Prerequisites (in terms of CS courses)

A selection of documents can be provided on request:

- Quantum mechanics

Basic quantum mechanics, wave functions, amplitudes and probabilities. Commutation relations between coordinates and corresponding momenta. Schrödinger and Heisenberg pictures. Dirac bra and ket formalism. Idea of spin. Cross-sections and scattering amplitudes. Fermions and bosons. This corresponds to the content of the first year quantum mechanics course.

- Relativistic kinematics

Lorentz transformations. Minkowskian spacetime, metric tensor and 4-vectors. 4-momentum and energy-momentum conservation. Sections 3.1-3.4 of Griffiths, or sections 3.1-3.2 of Halzen-Martin present these topics at an appropriate level.

- Electrodynamics

Manifestly covariant formulation of classical electrodynamics using the field-strength tensor and Lagrangian density. Dirac equation. Prerequisite are best explained in sections 7.1, 7.4, 11.1 and 11.2 of Griffiths. See alternatively sections 5.1, 5.2 and 14.1 of Halzen-Martin.

- Mathematical tools

Basic use of the Dirac distribution and Fourier transform. Basic properties of groups and idea of a linear representation. Basic use of tensor calculus, including Einstein's summation convention. Chapters 3.2, 4.1, 4.2 and appendix A of Griffiths are adapted to the level of the lectures.

Class components (lecture, labs, etc.)

16 classes of 1h30 each. Recommended reading to prepare a session. Homework assignments to acquire the necessary calculation techniques.

Grading

Homeworks and final oral exam.

Course support, bibliography

- J.S. Bell, *Experimental Quantum Field Theory*, CERN-JINR School of Physics, 1977.
- S. Chatterjee, *Yang-Mills for probabilists*, arXiv:1803.01950 [math.PR].
- B. Delamotte, *A hint of renormalization*, http://arXiv.org/pdf/hep-th/0212049.
- M.R.Douglas, *Report on the Status of the Yang-Mills Millenium Prize Problem*.
- D.Griffiths, *Introduction to Elementary Particles*, John Wiley & Sons, 1987 (first edition).
- F. Halzen and A.D. Martin, *Quarks and Leptons: An Introductory Course in Modern Particle Physics*, John Wiley & Sons, 1984.
- A. Jaffe and E. Witten, *Quantum Yang-Mills theory*.
- F. Mandl and G. Shaw, *Quantum Field Theory*, John Wiley & Sons, 1993 (revised edition).
- M.E. Peskin and D.V. Schroeder, *An Introduction to Quantum Field Theory*, Addison-Wesley, 1995.
- R.J. Rivers, *Path Integral Methods in Quantum Field Theory*, Cambridge University Press, 1988.
- L.H. Ryder, *Quantum Field Theory*, Cambridge University Press, 1996 (second edition).
- J.J. Sakurai, *Modern Quantum Mechanics*, Addison-Wesley, 1985.
- F. Wilczek, *What QCD tells us about nature - and why we should listen*, http://arXiv.org/pdf/hep-ph/9907340.
- E. Witten, *The Problem of Gauge Theory*, http://arxiv.org/pdf/0812.4512v3.pdf.

Resources

Classroom courses, worksheets.

Learning outcomes covered on the course

At the end of this course, the student will be able to compute Feynman diagrams for scalar field theory at tree level, understand the formulation of QED, and grasp the mathematical complexity underlying quantum field theory.

3PN3150 – Topics in mathematics of physics

Instructors : **Igor Kornev**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

The fundamental laws of nature are geometrical rather than algebraic. This course introduces students to some of the key concepts of modern theoretical physics. The aim of this course is to achieve an understanding and appreciation of geometrical methods in physics.

Quarter number

SG11

Prerequisites (in terms of CS courses)

1SL3000 (Quantum and statistical physics). Significant progress towards a degree in math, physics, or engineering.

Syllabus

1. Classical Mechanics vs Symplectic Geometry. In fact symplectic geometry arose from the study of optics. When a ray of light propagates through an optical system, its direction is changed and the change in direction corresponds to a symplectic matrix that preserves a "symplectic structure." We will address the question of why symplectic geometry is the natural setting for classical mechanics.
Reference Math: [1]; Reference Phys: [2]

2. Gravitation vs Riemannian Geometry. What does the motion of a free particle have to do with geodesics in a Riemannian or pseudo-Riemannian manifold? What is needed for Relativity Theory? Can, e.g., gravity in 2D be entirely topological?
Reference Math: [3]; Reference Phys: [4]

3. Physical Fields vs Bundles.
Why does a physicist care about any of this bundle business? We will discuss electromagnetism, gauge elds and connections on principal bundles, magnetic monopoles as mathematically nontrivial principal bundles and the Hopf fibration.
Reference Math: Ch. 9 of [5]; Reference Phys: Vol. 3 of [6] and Ch. 15 of [7]

4. Geometrical Berry Phase vs Holonomy.
What, e.g., holonomy of the U(1) connection has to do with the Aharonov-Bohm effect.
Reference Math: Ch. 10 of [5]; Reference Phys: Vol. 3 of [6]

5. Forces and Potentials vs (Co-)homology. De Rham Theory in Electromagnetism.
We will discuss how to think about homology and cohomology, what, e.g., (co-)homology has to do with electrical conductance or with the BRST symmetry.
Reference Math: [8] and Ch. 6 of [5]; Reference Phys: Ch. 13 of [9] and Vol 1, Ch. 16.8 of [6]

6. Topological Insulators vs Homotopy.
We will discuss the homotopy classification of topological insulators.
Reference Math: [8]; Reference Phys: Vol. 1, Ch. 5 of [6]

7. Defects vs Algebraic Topology.

The idea is to turn topology into algebra problems and solve them using algebra.
Reference Math: Ch. 4 of [5] and [8]; Reference Phys: Ch. 9 of [10] and [11]

8. Topological quantum field theory vs Categories.
How functors, categories, cobordisms, and vector spaces t together into the topological quantum field theory.
Reference Math: [12]

Class components (lecture, labs, etc.)

Lectures + questions from students
Reading assignments
In class problem solving
Weekly homework assignments

Grading

Distribution of credits: Homework 40% (due in 7 days after it is assigned; 5 point off for each business day after deadline), Final 60%
Homework :
You have to show reasonable amount of work, instead of only showing the final results.
Specifically,
Write neatly
Show all intermediate steps
Use lots of words and explanations, not only equations
Always make sure that your answer makes physical sense
Remember to staple the pages!

Important note: you can feel comfortable that you have truly mastered a problem if, and only if, you are able to explain it in detail.
Credit will be given only if the reader can easily follow the arguments.

Final : a half hour presentation

Course support, bibliography

The textbook for this class is: M. Nakahara, Geometry, Topology and Physics, Institute of Physics Publishing, Philadelphia, 1990

Resources

Instructor: I. Kornev
The textbook for this class is: M. Nakahara, Geometry, Topology and Physics, Institute of Physics Publishing, Philadelphia, 1990

Learning outcomes covered on the course

Understand the concepts of geometrical methods and their role in modern physics.
Analyse physics problems using appropriate techniques from group theory and differential geometry.
Apply their knowledge to diverse situations in physics and engineering

Description of the skills acquired at the end of the course

Demonstrate an understanding of the basics of geometrical methods in modern physics ;
Develop problem solving skills on topics included in the syllabus

3PN3160 – Quantum simulation of materials

Instructors : **Charles Paillard**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS, FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

From understanding electrons to materials design
It is today possible to predict numerous functional properties of materials without resorting to experimental data. Advanced theories allow for the numerical design of materials before their synthesis. As a result, extensive databases of "digital materials" have been created (materialsproject.org). Machine learning techniques are also being employed for the discovery of new materials. It has been made possible due to progress in the theoretical and algorithmic domains, as well as the advent of increasingly powerful supercomputers.
One of the most popular modeling techniques relies on Density Functional Theory (DFT), to numerically solve the quantum problem of electron interactions. By using electron properties, which are responsible for chemical bonds, numerous material properties can be deduced.
In this course, we will focus on the foundations and applications of DFT to understand and numerically compute various material properties (structural, magnetic, thermodynamic, ...). A large part of the course will be devoted to hands-on sessions.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Quantum Mechanics, Solid State Physics (crystallography, band structure), thermodynamics

Syllabus

- Introduction to DFT: theory and implementation
- DFT: algorithms and High-Performance Computing
- Nuclei-electron interactions
- Density Functional Perturbation Theory for linear responses of materials
- Phase stability and phase transition: thermodynamics of materials
- Electronic properties from DFT: magnetism, metal or semiconductor?
- DFT and machine learning

Class components (lecture, labs, etc.)

Lectures and hands-on session using the open-source package ABINIT

Grading

Oral presentation on a practice project.
The first two lectures are necessary to be able to properly understand the course. Students absents for the first two lectures will be considered to drop out of the course.

Resources

- Lecture slides and bibliography references therein
- Hands-on sessions to learn how to use the ABINIT open-source software (abinit.org) to simulate various microscopic properties of matter.

Learning outcomes covered on the course

- Understand the quantum foundations of DFT
- Understand the importance of electrons in functional properties of materials
- Learn how to compute a physical property of various materials

Description of the skills acquired at the end of the course

Be able to use a DFT code to model materials properties ol {margin-bottom:0cm;}ul {margin-bottom:0cm;}

3PN3500 – Scientific project

Instructors : **Thomas Antoni**
Department : **MENTION QUANTUM ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

Alone or in pairs, you will devote yourself to a concrete and in-depth study of a real problem of physics. You can propose a subject yourself or choose one from a catalog of proposals from the School's partners or laboratories. Except in special cases, you will work in the premises and among the staff of the supervising organization in order to allow you to discover a new working environment and to refine your professional skills.

The duration of the project is equivalent to one and a half months of full-time work (144 hours on the schedule and 96 hours off the schedule).

In order to allow you to start your project with a sufficient background and to give you the conditions to work on it regularly, our mention has arranged its schedule so that you can devote one and a half consecutive days per week from January to April.

Quarter number

SD9 SG10 SG11

Prerequisites (in terms of CS courses)

None.

Syllabus

Projet.

Class components (lecture, labs, etc.)

Projet.

Grading

Final report and defense.

Resources

Project. Tools to be defined with the advisor.

Learning outcomes covered on the course

Gaining autonomy in the treatment of a real scientific problem and the production of results. Deepening of a theme.

Description of the skills acquired at the end of the course

(C1.2) Identify, formulate and analyze a problem in its dimensions scientific, economic and human.
(C1.3) Use and develop appropriate models, choose the right scale modeling and simplifying assumptions relevant to addressing the
problem.
(C1.4) Solve the problem with a practice of approximation, approximation of the simulation and experimentation.
(C1.5) To specify, design, build and validate all or part of a complex system.
(C1.6) To mobilize a broad scientific and technical base in the framework of a transdisciplinary approach.
(C2.1) Have an in-depth knowledge of a field or discipline related to the sciences. Transpose to other fields, such as fundamental or engineering sciences.
disciplinary, generalize knowledge. Rapidly identify and acquire new knowledge and necessary skills in the relevant fields, whether they are
technical, economic or other. To create knowledge, in a scientific approach.
(C2.2) To master the skills of one of the basic professions of the engineer (at junior level).
(C3.2) To have the culture of performance, to be realistic, pragmatic.
(C3.3) Be agile, creative, accept failure, question oneself, resilient, decisive.
(C3.4) Desire to have impact, ambition, passion, envy, see the glass half full, solution-oriented.
(C3.5) Knowing how to recruit all interested parties, knowing how to manage, being in the other's frame of reference, knowing how to listen, empathy.
(C3.6) To lead a project from start to finish, to have a 360° vision.
(C3.5) Be proactive, take initiatives, know how to mobilize resources, be an entrepreneur in your own right.
(C3.8) Make decisions in a partially known environment, manage the unexpected, know how to take risks.
(C3.10) Propose new solutions/tools, either broken or in continuous progress.
(C3.12) Evaluate the effectiveness, feasibility and robustness of proposed solutions.
(C3.13) Select solutions and act pragmatically to achieve tangible results.
(C4) Perceives the goals Think customer. Identify/analyze the needs, issues and constraints of other stakeholders, especially societal and socio-economic.
Knowing how to discern opportunities, good business opportunities and seize them.
(C5.2) Listen, understand and be understood by various audiences (professions, cultures, etc.) by
using appropriate means of communication. Work with actors of very different cultures, experience and skills
Propose adapted solutions that can be deployed in a
(C6.1) Identify and use on a daily basis the software necessary for their work (including collaborative work tools).
(C6.8) Understand the limitations of software solutions (numerical simulations, algorithms, machine learning...) and what can be expected from them.
(C6.9) Exploit all types of data, structured or not, including massive data.
(C7.1) Convince on the substance. Be clear about the objectives and expected results. Be rigorous about assumptions and approach. Structure your
ideas and its argumentation. Highlight the value created.
(C7.2) Convince by working on the relationship with the other. To understand the needs and expectations of his interlocutors. To take into account
evolutionary way. Encourage interaction. Create a climate of trust.
(C7.4) Master the spoken and written language. Master basic communication techniques.
(C8.1) Work in a team/collaboration.
(C8.4) Work in project mode using project management methods appropriate to the situation.

COMMUNICATING SYSTEMS AND INTERNET OF THINGS MAJOR (SCOC)

3SQ1010 – Challenges and issues of information and communication technologies

Instructors : **Armelle Wautier, Catherine Soladie**
Department : **DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Information and communication technologies (ICT) are constantly evolving and at the heart of current societal issues. The aim of this module is to discover the stakes, challenges and technological mutations in various sectors of activity such as health, transport, energy, space, the industry of the future, smart cities or sustainable territories. It presents a global vision of developments in these fields, covering regulatory, scientific and geopolitical aspects. The course also takes into account the changing needs of markets due to digital transformation and sustainable development.
Through lectures, case studies, round tables, tours and mini-forums, you'll be able to discuss with experts the future of ICT and the impact of new technologies (internet of things, xG, cloud computing, artificial intelligence, virtual reality, etc.). This course enables you to grasp the complexity of connected systems at different levels, to understand the synergies between stakeholders and to discover the variety of professions through teaching activities centered on the business world.

Quarter number

SD9

Prerequisites (in terms of CS courses)

none

Syllabus

Courses are taught in three main directions: regulatory bodies, markets and geopolitical issues surrounding new information and communication technologies, and the development of connected systems. These items are applied to different business sectors (space telecommunications, smart cities, connected products, transport, etc.).

Class components (lecture, labs, etc.)

Teaching takes the form of lectures, conferences, case studies, mini-forums and visits. Numerous exchanges with professionals from different fields are offered. Attendance is compulsory and active involvement is solicited.

Grading

Students participate in the organization and welcoming of speakers. Assessment is based on a personal summary of the themes covered in the module's activities, participation in an interview related to the professional project, and attendance at the various activities.

Resources

This module is mainly led by experts in the various fields.

Learning outcomes covered on the course

At the end of this course, students will be made aware of technological challenges and the issues of several fields of application of communicating systems, connected objects and ICT.
The learning outcomes are :
- understand the complexity of connected systems
- understand and identify the challenges of digital transformation
- understand the variety of professions
- know the main actors and their synergies (operators, manufacturers, equipment suppliers, consultants, regulators etc.)
- know the changing business issues due to digital transformations and sustainable developments
- to mature one's professional project

Description of the skills acquired at the end of the course

C1 Analyze, design and build complex systems with scientific, technological, human and economic components.
C7 Convincing
C8 Manage a project
C9 Think and act as an ethical, responsible and honest engineer, taking into account environmental, social and societal dimensions.

3SQ1025 – Signal Processing for communications, image and audio

Instructors : **Haïfa Jridi, Jose Picheral**
Department : **DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES, CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

The digital signal processing plays a central role in the field of communication systems and connected objects. Indeed, the theory of signal processing is of paramount importance in ensuring reliable transmission of information, taking into account the inherent physical and technological constraints. At the same time, the processing, analysis, and formatting of measured data rely on signal processing tools.
By combining theory and practice, this course will enable you to master the essential skills of signal processing in order to design, analyze, and optimize efficient communication systems and connected objects. You will be able to efficiently exploit data, make informed decisions, and contribute to the advancement of communication and connectivity technologies.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Signal processing

Syllabus

This course explores various applications in the fields of communication, image processing, and audio to highlight the practical use of fundamental signal processing tools. We will start by studying the definitions and theoretical properties of digital signal processing and then apply them through concrete applications.

Throughout this training, we will cover key concepts such as filtering, projection, signal orthogonality, and frequency representation of signals. These concepts will be applied in specific contexts such as synchronization, transmission, compression, and information extraction from signals.

Class components (lecture, labs, etc.)

Lectures, tutorials and practical/laboratory work

Grading

Final written exam (70%/C2.1,C2.5, C6.7), evaluation of practical/laboratory work (30%/C1.4) with -2 penalty in case of absence at a session.
Some of the skills (in particular C1.4) will be assessed during the practical/laboratory work.

Course support, bibliography

J. G. Proakis, "Digital Communications", Fourth Edition, McGraw Hill, 2001.
T. Cover, "Elements of Information Theory", 1991
D. Tse, P. Viswanath, "Fundamentals of Wireless Communications", CambridgeUniversity Press, 2005.

Resources

- Teaching team at Rennes: Haïfa Farès, Yves Louët.
- Language of instruction at Rennes: French, English
- Teaching team at Saclay :José Picheral, Jacques Antoine
- Language of instruction at Saclay : French

Learning outcomes covered on the course

- Use signal processing tools for applications in image and audio communication.
- Master the theoretical tools of signal processing.

Description of the skills acquired at the end of the course

C1.4 Specify, design, build and validate all or parts of a complex system
C2.1 Deepen on a field or discipline related to the basic sciences or the engineering sciences
C2.5 Master the skills of one of the basic engineering professions
C6.7 Understand the theory of information transmission

3SQ1030 – Digital communications

Instructors : **Haïfa Jridi, Jacques ANTOINE**
Department : **DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY, CAMPUS DE RENNES**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Signal processing and information transmission are at the junction of the physical and digital worlds. Applications are in many fields: telecommunications, positioning systems, radar, transportation, space, energy, health, environment, virtual reality, and connected objects.
The objective of this course is to master mathematical tools and methods to design processing chains at different levels of a system. Topics include modulation techniques and communication system designing. The concepts are illustrated by exercises and numerical simulation with hands-on programming in Matlab.
This course is a prerequisite for other courses.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Model Representations and Analysis ; signal processing

Syllabus

- Modeling of a communication at different levels, Physical channel models
- Modulation techniques: waveforms, carrier frequency, modulation, constellation
- Diversity techniques, Reception theory.
- Synchronization, Channel estimation, Equalization, Detection
- Transmitter and receiver design compromises
- Multi-carrier systems (OFDM)
- Energy saving waveforms
- Communication system sizing: energy, environment, signal-to-noise ratio, throughput, latency, spectrum, reliability, security
- Modeling and simulation via Matlab of standard communication systems

Class components (lecture, labs, etc.)

Lectures (10h30), tutorials (4h30) and practical/laboratory work (7h30)

Grading

Final written exam (1h30) (70%), evaluation of practical/laboratory work (30%) with -2 penalty in case of absence at a session
Skills are evaluated during the practical/laboratory work

Course support, bibliography

J. G. Proakis, "Digital Communications", Fourth Edition, McGraw Hill, 2001.
R. Van Nee & R. Prasad, "OFDM for wireless multimedia communication", Artech House Publishers.
A. F. Molish, "Wireless Communications", Wiley-IEEE Press, 2005.

A. J. Goldsmith, "Wireless Communications", Cambridge University Press, 2005.
D. Tse, P. Viswanath, "Fundamentals of Wireless Communications", CambridgeUniversity Press, 2005.

Resources

Teaching team at Gif: Jacques Antoine, Armelle Wautier, José Picheral, Raul De Lacerda. Dinh Thuy Phan Huy
Language of instruction at Gif : French
Teaching team at Rennes: Haïfa Farès, Yves Louët.
Language of instruction at Rennes: English

Learning outcomes covered on the course

At the end of the course, students will be able to:
- understand the fundamental concepts of signal processing and transmission of information for communicating systems
- design and model a whole, or parts of a, communication system and to assess the communication system performance either analytically or by simulation
- determine or optimize the paremeters of a communication system (e.g., choice of operation architecture, information processing algorithms, dimensioning) such as to meet the
needs of an application while satisfying physical, energy, environmental, technological, economic or regulatory constraints ...

Description of the skills acquired at the end of the course

C6.7 Understand the theory of information transmission
C1.2 Use and develop suitable models, choose the right modeling scale and simplify hypotheses to deal with a problem
C1.4 Specify, design, build and validate all or parts of a complex system
C2.1 Deepen on a field or discipline related to the basic sciences or the engineering sciences
C2.5 Master the skills of one of the basic engineering professions

3SQ1040 – Embedded systems

Instructors : **Anthony Kolar**
Department : **DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The objective of this course is to enable students to understand the complexity of embedded systems design as a whole, starting from the basics and developing the knowledge up to recently developed technologies.

The theme of embedded systems is very vast but this course will try to organize itself around 3 main ideas:

1- First of all from a technological point of view: what are the technologies that are used, what are their main differences and in which case to use one or the other of these technologies. This will be the so-called material aspects.
2- The 2nd axis is that of the tools and the development environment: when and how to choose a tool or a development environment adapted to a specific use case.
3- Finally, the 3rd axis is an opening towards the future where we will apprehend new development platforms and new design approaches. We will focus on two aspects:
  a- the first one is the hardware hybrid platforms
  b- the second aspect is the use of artificial intelligence, but not only from a software point of view but also from a hardware point of view in order to optimise performance.

Quarter number

SD9

Prerequisites (in terms of CS courses)

This course requires a minimum of prerequisites:

1- Minimum knowledge of digital electronics
2- Minimum programming knowledge

Syllabus

This course is made up of two main parts:

A- Programming in C language

1- Theory of language
2- Putting it into practice by Project approach

B- Embedded systems

1 - Processors: CPU and GPU [For those who have not done elective 2A "Digital Systems Architecture"]
    1.1 The CPUs: The basic constituent elements, the architectures mainly used in embedded, the instruction sets, opening towards other architectures
    1.2 The compiler: how does a "written" code make it possible to program a processor?
    1.3 Graphics processors: NVIDIA architectures, parallel computing

1- Professor RISC V [For having done elective 2A "Architecture of Digital Systems"]
    1.1 Focus on RISC processor families
    1.2 RISC V: Architecture and Specificities

2 - Specialized components: FPGA and ASIC
    2.1 ASICs and FPGAs: Definitions and Differences
    2.2 Design Flow: how to design and simulate?
    2.3 Optimization: Case study - Constraints and comparison

3 - Environment and development tool
    3.1 CPU and GPU: When, how and which language to use with what consequences? a.k.a Python vs C/C++
    3.2 FPGA and ASIC: Design approaches and their evolutions (HDL vs HLS). ASIC VS FPGA design tools

4 - System on Chips
    4.1 SoC hybrid architectures: definition, philosophy and uses
    4.2 Case study: the Zynq Book

5 - Material Artificial Intelligence or how to make AI really efficient in the embedded world

Class components (lecture, labs, etc.)

1- Course
2- Case study in class
3- Personal work

Grading

The evaluation will cover the entire course program and assess your ability to reflect and step back on the field studied.

The skills will be validated if and only if all of the evaluation scores are greater than 10.

Resources

The learning of the C language will be done via a Project-type approach
The rest of the course will be done with a classic teaching approach but promoting exchange during the sessions.

Learning outcomes covered on the course

1- Acquisition of knowledge of programming in C language
2- Understanding of design and programming in the embedded world
3- Acquire a vision of the evolution of technologies and its impact on the current designer's work
4- Know how to choose the right development tools according to the situation and the desired level of performance
5- Approach artificial intelligence from a hardware prism and not only from a software one

Description of the skills acquired at the end of the course

C1.1 Study a problem as a whole, the situation as a whole. Identify, formulate and analyze a problem in its scientific, economic and human dimensions.
C1.3: Solve the problem with a practice of approximation, simulation and experimentation.
C1.4: Design: specify, produce and validate all or part of a complex system

3SQ1041 – Embedded systems

Instructors : **Amor Nafkha**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES), DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

An embedded system is an autonomous electronic and computer system dedicated to a specific task with a limited size and low energy consumption. Embedded systems engineering is a discipline which designs and implements hardware and software of embedded systems and it is used in industries such as aerospace and defense, energy, industrial automation, health care, networking and communication, security, transportation and more. This course will provide students with the opportunity to develop practical skills and theoretical knowledge in embedded systems engineering, including embedded systems programming, embedded real-time operating systems as well as embedded hardware engineering.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Programming concepts in C language;
Basic knowledge of digital electronics;

Syllabus

The following concepts will be discussed in detail and illustrated by practical labs or demonstrations:

+ Microcontroller Architecture
+ General Purpse I/O and general Purpose Timers
+ Real-time Clock (RTC)
+ Software Development Platforms
+ Interrupts & Power management
+ Timing & Memory operations
+ Debugging tools for embedded systems
+ Fundamentals of Real-Time Operating Systems
+ FreeRTOS: Task, event, mutex, semaphore and Queue
+ Software Timers in FreeRTOS
+ Memory management in FreeRTOS

==> Practical Labs/ projects: STM32 Platforms with STM32CubeIDE or Keil microVision IDE

Class components (lecture, labs, etc.)

Lectures to introduce the basic concepts and general principles.
Applications will be studied during TD and will be tested on development boards during practical experimental sessions

Integrated Development Environments:

- STM32CubeIDE & STM32CubeMX IDE
- Keil microVision IDE

Grading

The course evaluation will relate to the work done in Labs (session evaluation and written report)

Course support, bibliography

Course materials (handouts and other educational resources) will be made available on Edunao and on a drive (OneDrive).

Bibliography :
1- Zhu, Y. Embedded Systems with ARM Cortex-M3 Microcontrollers in Assembly Language and C; E-Man Press LLC: Ballston Spa, NY, USA, 2014;
2- Brian Amos. Hands-On RTOS with Microcontrollers: Building Real-Time- Embedded Systems using FreeRTOS, STM32 MCUs, and SEGGER Debug Tools. Packt Publishing Limited, Birmingham, United Kingdom, 2020;

Resources

Each student will have a development card based on an ARM cortex-M microcontroller (STM32) associated with integrated development environments: STM32CubeMX, STM32CubeIDE, STM32CubeProgrammer, Keil microVision IDE.
Various sensors and converters (e.g., USB-RS232) will be made available for students to carry out their practical work or activities in the field of embedded systems.

Learning outcomes covered on the course

At the end of this course, students will be able to:
1- Understand integrated development environments (IDE) and energy consumption issues for embedded systems;
2- Understand internal MCU hardware architecture;
3- Understand and control the interruption mechanisms (causes, hardware interruptions, software interruptions, interruption processing,...) and debugging;
4- Design and implement a real-time embedded system (tasks, mailboxes, semaphores,...);

Description of the skills acquired at the end of the course

C1.1 Study a problem in its entirety, the situation as a whole. Identify, formulate and analyze a problem in its scientific, economic and human dimensions.

C1.3: Solve the problem with a practice of approximation, simulation and experimentation.
C1.4: Design: specify, perform and validate all or part of a complex system
C2.3 Identify and quickly acquire new knowledge and skills necessary in the relevant fields, whether technical, economic or other.
C2.5 Conducting a project in a professional context
C3.3: Decide, initiate, carry out and commit to an ambitious high impact project, deliver tangible results, be pragmatic

3SQ1050 – Wireless transceiver architecture

Instructors : **Mohammed Serhir**
Department : **DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

The objective of this module is to introduce design techniques for radiofrequency devices. It will focus on the analysis of radio transmitter - receiver (transceiver) architectures using a conceptual and methodological approach. From the component at CMOS level to the architecture of the subsystems, the students are made aware of the analysis and synthesis methods of the most commonly used functional blocks. The important stages (amplifier, mixer, coupler, oscillators) in radio transceiver architectures will be described taking into account noise and following a comparative and operational approach.

This course is naturally linked to the other modules of the sequence (embedded systems, communication systems, IoT design). It aims at giving RF architectural engineers the tools/methods to :

- Predict the performances and elaborate the technical specifications of RF systems and subsystems,
- Assess the relevance of radiofrequency solutions according to the targeted applications: space (payload), autonomous vehicle (consumption, performance), miniaturization and device integration (electromagnetic compatibility).

At the end of this course, students will be able to analyse/size the specifications of an radio transceiver to meet the trade-offs: power consumption / performance / dynamics / sensitivity.
From the specifications to the model, this course aims to make the interconnection between man and the digital world transparent.

Quarter number

SD9

Prerequisites (in terms of CS courses)

- Signal processing, Fourier transformation, Filtering
- Anlog and digital moduation
- Wave physics, radiation and propagation, Fields and propgations
- Electronic systems
- Digital communication

Syllabus

Introduction: an overview
Function blocks (system view)

- Amplification / Mixing
- Filtering / Detection
- S parameters

Linearity in transceivers
Time variation, systems with and without memory, harmonic distortion, compression, interference and IP3 intermodulation,

Radio architecture: part1
Introduction, modulation and architecture, analog modulations, digital modulations, intersymbol interference, constallation, optimization/bandwidth, quadrature modulation, specifications

Radio architecture: part2
Filtering, coupling/isolation in Tx-Rx stages, Heterodyne solution, image frequency management/local oscillator, double transposition Heterodyne solution, modern Heterodyne, direct conversion

Noise analysis in radio architectures
Noise modeling, signal-to-noise ratio, noise figure of a receiving chain

Class components (lecture, labs, etc.)

- 6 Lectures
- 3 tutorials

Grading

- Written exam at the end of this course (1h30)
- Skill C.1 is evaluated through one of the exercises of the final written exam. If the grade for this exercise is higher than 50%, the student will have validated the C.1 skill in this course.
- Skill C.3 is evaluated through one of the exercises of the final written exam. If the grade for this exercise is higher than 50%, the student will have validated the C.3 skill in this course.

Course support, bibliography

- Microwave and RF Design, M. Steer,
- Microwave Engineering, D. M. Pozar
- RF Microelectronics, B. Razavi
- CMOS Wireless Transceiver Design, J. Crols, M. Steyaert
- RF Circuit Design, Theory and Applications, R. Ludwig, P. Bretchko

Resources

Teaching team :
- Saclay Campus : M. Serhir, I. Hinostroza
- Rennes Campus : H. Farès, A. Nafkha, R. Salvador

TD size (default 35 students): 2 groups in Saclay, 1 group in Rennes

Learning outcomes covered on the course

The "Radio Architecture " course will provide students with the necessary knowledge to :
- Analyse the usual architectures of transceivers and justifying their limits
- Size/specify the right RF components for a specific application
- Prioritize design constraints on transmitting/receiving stages
- Model and evaluate noise in a radiofrequency Tx-Rx systems

Description of the skills acquired at the end of the course

- C1.2: Know how to use a model presented in class in a relevant way (amplifiers and mixers analysis)
- C1.3: Solving the problem using appropriate approximations and simulations (non-linearities in transceivers)
- C1.4: Specify and design part of a system (matching between the transceiver architecture and the used signal modulation)
- C3.7: Assess the effectiveness, feasibility and robustness of proposed solutions

3SQ1061 – Policy, Funding, Regulations and Standards for TechForGood industries

Instructors : **Renaud Seguier**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

How to sell healthcare in France? What is a class 2 DM (medical device)? Is it mandatory? How long does it take? And how much does it cost?
I want to make people aware of the need to change their consumption habits. Should I create or join an association? Or a company? Can I make a living from it? How can we ensure that effective legislation on the subject is passed?
To answer these questions, and many others, a number of people in the business will come and explain what they've set up, the difficulties they've encountered, their successes, and the constraints they face. Through these discussions, you'll refine your understanding of the global ecosystem of TechForGood companies, because the success of a project, of a company, is the success of all these players, within a complex ecosystem.

Quarter number

SD9

Prerequisites (in terms of CS courses)

None

Syllabus

Financing (20%)
- Competitiveness clusters,
- Calls for government projects
- Private financing

Regulations (20%)
- Biodiversity
- Animal welfare
- Health

Medical devices (10%)
- CE marking (Europe) versus FDA (USA)
- Research protocol

Project (50%)
- Work on a customized project: Class IIa CE medical device

Class components (lecture, labs, etc.)

Testimonials from outside contributors (regulations, financing)
Flipped classroom: "from scratch" creation of a research protocol

Grading

Report (40% of final grade) (C3, C5)

Presentation of practical work (50% of final grade) (C3, C5)
90s pitch on chosen project (10% of final grade)(C7)

Resources

Teaching team :
- Renaud Seguier
- Outside contributors

Learning outcomes covered on the course

At the end of this course, students will be able to:

- understand the procedures to be put in place to carry out a clinical research protocol and submit it to an ethics committee
- list the tools used to finance medical devices
- Identify and understand current clinical trials in Europe and the USA on a given subject.

Description of the skills acquired at the end of the course

C3.2: Propose alternatives, formulate ideas by integrating the necessary external expertise (technical, commercial, HR, financial, legal, etc.), integrate risks and uncertainty.
C3.3: Implement innovative ideas and commit to decisions, evaluate solutions, industrialize and deliver tangible results.
C5.2 : Listen, make oneself understood and work with people from different backgrounds, cultures, codes, training, disciplines, etc.
C7.1 : Substance: Structure ideas and arguments, summarize (hypotheses, objectives, expected results, approach and value created).

3SQ1070 – IoT application design

Instructors : **Pietro Maris Ferreira**
Department : **DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The objective of this course is to put the students in a situation of designing an Internet of Things application by experimenting, realizing and validating a functional demonstrator. Technological and methodological contributions as well as a practical application in project mode will allow us to understand the different components of a connected system from the choice of sensors to data processing.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Students must have a basic knowledge of programming (knowledge of a structured computer language such as java, Python or C). They must have taken the beginning of the dominant embedded systems course (introduction to C/C++).

Syllabus

The first classes will be devoted to tutorials to learn the necessary concepts (programming, development environment, cloud), ...
The other classes will be spent on implementing the project.

Students will work in teams.

In the teams, the students will share the work on issues around several axes:
- Electronic design and integration (sensor)
- Processing and communication (C programming, processing on on-board card, implementation of the communication protocol)
- Data processing and application on C server via Matlab

Students will have a set of components (sensors, treatment cards, etc.) that they can choose from a panel provided by the school.
The first step is to specify a target connected object and application.
The second step will be to assemble and integrate the different elements to create the object (sensors and processor)
In parallel, the third step is to develop the target application in the cloud.
Students must provide a functional demonstrator at the end of the project.

Class components (lecture, labs, etc.)

The teaching is done in the form of several tutorials for the discovery of the constituent elements of the object and a project supervised by teachers.

Grading

At the end of the 3rd session, the students make an oral presentation of the concept they have imagined. The supervisors then give them feedback on the relevance of the project and the possibility of completing it in a reasonable time.
At the end of the project, the students present their work (oral presentation followed by a demonstration). They are evaluated on the technical quality of the work (functional demonstrator or not), the consideration of remarks during the intermediate presentation, and the quality of the oral presentation.

Course support, bibliography

Tutoriel Polycopié proposé par l'équipe enseignant.

Resources

Students will each have an electronic development card associated with a development environment:
On Saclay campus: ST-Discovery-L475E-IOT01A card and MBED-OS development environment

For the realization of the system, the students will have a panel of sensors.

Learning outcomes covered on the course

At the end of this course, students will be able to program a simple application in C language on an embedded processor. They will be able to connect an embedded system on a WIFI or Lora type network and finally will be able to simply process data recorded on a cloud.

Description of the skills acquired at the end of the course

C4: Have a sense of creating value for your company and its customers
C7: Know how to convince
C8: Lead a project, a team

3SQ1071 – IoT application design

Instructors : **Amor Nafkha**
Department : **DOMINANTE - SYSTÈMES COMMUNICANTS ET OBJETS CONNECTÉS**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The aim of this course is to put students in the position of designing a complete Internet of Things application based on the following three modules: 3SQ1041, 3SQ3070 and 3SQ3140. This module will be carried out in the form of a project in which the student will be required to define a specification with the teacher, design, experiment with and validate an end-to-end IoT application through a demonstrator: from the sensor(s) to the visualisation software interface.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Modules:
3SQ1041 Systèmes embarqués
3SQ3070 Sensors and communication interfaces
3SQ3140 IoT Platforms

Syllabus

The sessions will be devoted to implementing the IoT application. Students will work in teams (two to three people)

Class components (lecture, labs, etc.)

Project-based teaching

Grading

At the end of the project, the students present their work (oral presentation followed by a demonstration).

Resources

The students will each have a development board (ESP32 and/or STM32-L475E-IoT and/or Raspberry Pi and/or Lora modules, etc.) associated with a set of sensors and an IDE development environment.

Learning outcomes covered on the course

At the end of this course, students will be able to:
+ Define a specification based on needs in one of the following areas: health, wildlife protection, wastewater treatment, air treatment, waste treatment, etc.
+ Define the IoT technology to be used
+ Collect, transmit, store and analyse the information sent by the sensors
+ Analyse the consumption of the proposed solution

Description of the skills acquired at the end of the course

C1: Analyse, design and build complex systems with scientific, technological, human and economic components
C2: Develop in-depth skills in an engineering field and in a family of professions
C4: Create value for the company and its customers
C6: Be operational, responsible and innovative in the digital world

3SQ2010 – Network science

Instructors : **Koen De Turck, Richard Combes**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Networks are everywhere in our modern daily life. In abstract terms, a network is a set of entities (referred to as nodes) linked by relationships (referred to as edges). This simple definition allows to capture and study many different examples and phenomena, of which we name but a few: social networks, communication networks, search engines, content recommendation systems, epidemic processes.

In this course, we propose a first introduction to the modern and fascinating field known as "network science", which is the study of complex networks, with the goal of understanding their structure.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Linear algebra; probability; statistics; basic Python programming

Syllabus

Tentative syllabus

I) Introduction: examples of real world complex networks from: computer science, biology, medicine, etc.
II) Random Graphs: introduction to the theory of random graphs, random graphs as models for complex networks, branching processes, random graph models
III) Phase Transition Phenomena: connectivity thresholds, giant connected components
IV) Scale-Free Networks and Small World Networks: examples in real world networks, power law degree distribution, preferential attachment
V) Community Structures in Networks: examples of community structures in real world networks, the stochastic block model, community detection algorithms
VI) Epidemic Processes: diffusion of information on graphs, models inference algorithms, diffusion strategies

Class components (lecture, labs, etc.)

This course consists of both lectures and lab classes in roughly equal parts.

Grading

The students will be graded based an exam given at the end of the course.

Course support, bibliography

Remco van Der Hofstad, "Random Graphs and Complex Networks", 2013
Albert-Lazlo Barabasi, "Network Science", 2016

Resources

This course will be taught by means of a mixture of traditional lectures and tutorial sessions where students will analyze networks using Python.

Learning outcomes covered on the course

After following this course, students will be able to:
- understand the basics of random graphs, in order to be able to model any complex network
- understand the structural properties of large complex networks: connectivity, detection of communities, degree distribution, and many others
- apply algorithms to data extracted from real, large-scale networks in order to understand their structure, make predictions on them and control their operation and/or dynamics.

Description of the skills acquired at the end of the course

C1.1 Studying a problem as a whole, the situation as a whole. Identifying, formulating and analyzing a problem in its scientific, economic and human dimensions
C1.2 Using and developing the appropriate models, choosing the right modeling scale and the relevant simplifying assumptions to deal with the problem
C1.3 Solving problems with a mind-set of approximation, simulation and experimentation

C2.1 Having studied a field or a discipline relating to fundamental sciences or engineering sciences.

C3.7 Choosing solutions and act pragmatically, with the goal of obtaining tangible results

C6.4 Solving problems using a computational thinking process
C6.5 Using all kinds of data sets, structured or not, including big data stes.

3SQ2030 – Game theory

Instructors : **Sheng Yang, Samson LASAULCE**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

This course aims at helping the students to understand how game theory can be used for analyzing, designing, and studying modern networks such as 5G wireless networks, smart energy networks, and social networks. Basic and advanced notions of game theory will be studied and connections with optimization, distributed optimization, optimal control, and multi-agent learning will be established.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Basic mathematical notions which are typically taught in Bachelor in Electrical Engineering programs.

Syllabus

Technically, the following aspects will be developped:

- Methodologies to study equilibria in games.
- Important special classes of games (e.g., potential games). Mathematical properties and applications.
- Repeated games.
- Coalitional form games.
- Multi-agent learning.

Class components (lecture, labs, etc.)

The approach of this course is largely based on discussing examples, applications, and case studies. Exchanges between the instructor and the students are encouraged.

Grading

Students will be asked to form groups (of 2-3 people), choose a scientific paper in a list of selected articles, and summarize it under the form of a didactical slide-based presentation.

Course support, bibliography

[1] M. Maschler, E. Solan, and S. Zamir. "Game Theory". Cambridge University Press. 2013.
[2] S. Lasaulce and H. Tembine. "Game Theory and Learning for Wireless Networks : Fundamentals and Applications". Academic Press. 2013.

Resources

- 12 hours of lecture including about 3 hours of tutorial work.
- The students will have the opportunity to study in details one scientific article and to team up with their colleagues to generate the presentation asked for the evaluation

Learning outcomes covered on the course

The objective of this course is threefold : to give a unified overview of game theory to the students (direct game theory and mechanism design, strategic form and coalition form, analysis and algorithms, etc); to provide students a systematic methodology to study equilibria in games ; to show to the students through fundamental case studies and applications (e.g., viral marketing in social networks, power consumption scheduling in smart grids, and interference management in 5G networks) how game theory is applied in practice.

Description of the skills acquired at the end of the course

C1 Analyse, design and build complex systems with scientific, technological, human and economic components
C2 Develop in-depth skills in a scientific or sectoral field and a family of professions

3SQ2040 – Reinforcement learning

Instructors : **Richard Combes**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Reinforcement Learning is a subfield of Artificial Intelligence which addresses how one can learn through trial-and-error. Not only is trial-and-error learning the main technique used by all living creatures in order to survive, but it is also the technique which enables to solve several important and hard engineering problems:
- teaching a computer to play chess and go, and beat the best human players ?
- teaching robots how to move across unknown environments, avoid obstacles and reach targets ?
- recommending contents (books, films, videos etc.) to millions of customers, so that each client gets recommended content that fits their interest ?

The goal of this class is to give an introduction to this fascinating and fast evolving field: from mathematical models and algorithm design, to theoretical and numerical performance of algorithms and their practical implementation.

Quarter number

SG11

Prerequisites (in terms of CS courses)

First year probability and statistics course. Basic knowledge of Python.

Syllabus

Lecture 1:
Part 1: A General Model For Reinforcement Learning: state, actions, rewards, applications of reinforcement learning.
Part 2: Multi-Armed Bandit Problems I: definitions, stochastic vs adversarial problems, EXP3 algorithm.
Lecture 2:
Part 1: Multi-Armed Bandit Problems II: Lai-Robbins bound, Upper Confidence Bound algorithm, Thompson sampling algorithm, structured bandit problems.
Part 2: Multi-Armed Bandit Problems III: implementation of algorithms in Python and practical performance.
Lecture 3:
Part 1: Markov Decision Processes I: definitions, Bellman equation, computation of optimal policies.
Part 2: Markov Decision Processes II: solving Markov Decision Processes online, the Q-learning algorithm and beyond.
Lecture 4:
Part 1: Markov Decision Processes III: curse of dimensionality, value function approximation, policy gradient
Part 2: Markov Decision Processes IV: implementation of algorithms in Python and practical performance.

Class components (lecture, labs, etc.)

Lectures + Python programming

Grading

Report to be handed out at the end of the course.

Course support, bibliography

Lecture Notes

Resources

Lectures + Python programming.

Learning outcomes covered on the course

With this course, students will have a firm grasp of the main algorithms used in reinforcement learning. They will understand their theoretical performance guarantees, as well as how to implement, and their actual performance.

Description of the skills acquired at the end of the course

With this course, students will have a firm grasp of the main algorithms used in reinforcement learning. They will understand their theoretical performance guarantees, as well as how to implement, and their actual performance.

3SQ2050 – Deep Learning

Instructors : **Juan-Pablo Piantanida**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

In the recent years, the use of Machine Learning algorithms to address many ill-posed problems in the field of multi-dimensional signal processing and big data analytics have gained importance. New methods for signal representation, modeling, optimization and leaning have been formulated, which spans over various areas of Machine Learning, Pattern Recognition, Vision, Natural Language Processing and Digital Communications.

This introductory course gives an overview of many concepts, techniques, and algorithms in machine learning, the principles of representation and deep learning in particular, beginning with topics such as classification and linear regression and ending up with more recent topics such as support vector machines, neural networks, auto-encoders, convolutional neural networks and recurrent networks. The course will give the student the basic ideas and intuition behind modern deep learning methods as well as a bit more formal understanding of how, why, and when they work. The underlying theme in the course is the area of deep learning, as it provides the foundation for most of the methods covered.

This course will provide an overview of the theories and current practices in the area of deep learning, required by students who intend to specialize in this field, to solve complex problems in Machine Learning with applications to engineering areas such as communications and Internet of thing (IoT).

Quarter number

SG11

Prerequisites (in terms of CS courses)

The underlying themes in basics courses of statistical inference, probability theory and optimization as it provides the foundation for most of the methods covered. In addition some Python programming experience is requested.

Syllabus

1. Introduction to Statistical Learning
- Introduction, linear classification, perceptron update rule
- Classification errors, generalization, regularization, logistic regression
- Linear regression, estimator bias and variance
- Support vector machine (SVM) and kernels, kernel optimization
- Model selection, description length, feature selection
- Clustering

2. Introduction to Neural Networks:

- Perceptrons, capacity of a single neuron
- Linear and logistic regression
- Backpropagation and stochastic gradient optimisation

3. Advance Neural Networks:
- Auto-encoders and variants
- Hyper-parameters and training tricks for neural networks
- Difficulty training deep networks and regularization (norms, Dropout, denoising auto-encoders,…)
- Unsupervised learning of representations and pre-training

4. Variations on Auto-Encoders and Recurrent Networks:

- Convolutional neural networks
- Recurrent networks
- Variational auto-encoders and Generative Adversarial Nets

5. Modern Architectural Variations with Applications to Communications and IoT Data Analytics:

- A quick view of TensorFlow
- Typical classification tasks: classifying MNIST digits using logistic regression
- Keras: a python deep learning library
- Deep learning for solving communication problems

Class components (lecture, labs, etc.)

Lectures, examples, lecture notes, relevant books, practical implementations based on dedicated projects, ...

Grading

There will be two exams, a class project in the midterm midway through the term and a final the last day of class. Students are required to complete a class project. The choice of the topic is up to the students so long as it clearly pertains to the course material. To ensure that students are on the right track, they will have to submit a one paragraph description of their project before the project is due. We expect a four page write-up about the project, which should clearly and succinctly describe the project goal, methods, and the results. Each group should submit only one copy of the write-up and include all the names of the group members (a two person group will have 6 pages, a three person group will have 8 pages, and so on). The projects will be graded on the basis of your understanding of the overall course material (not based on, e.g., how brilliantly the method works). The scope of the project is about 1-2 problem sets.
The projects can be literature reviews, theoretical derivations or analyses, applications of machine (deep) learning methods to problems you are interested in, or something else (to be discussed with course staff).

Course support, bibliography

1. **Deep Learning:** by Ian Goodfellow, Yoshua Bengio and Aaron Courville, Adaptive Computation and Machine Learning series, MIT Press, November 2016, ISBN-10: 0262035618.
2. **Machine Learning: A Probabilistic Perspective,** by Kevin P. Murphy, Adaptive Computation and Machine Learning series, MIT Press, ISBN-10: 0262018020.
3. **Understanding Machine Learning: From Theory to Algorithms,** by Shai Shalev-Shwartz and Shai Ben-David. 2014, Cambridge University Press, USA.
4. **Deep Learning - Methods and Applications,** by Li Deng and Dong Yu http://research.microsoft.com/pubs/219984/BOOK2014.pdf
5. **Torch7:** http://torch.ch/
6. **TensorFlow:** https://www.tensorflow.org
7. **Tools:**
    - http://keras.io/
    - https://www.cs.cmu.edu/~ymiao/pdnntk.html
    - http://deeplearning.net/software/pylearn2/
    - http://blocks.readthedocs.org/

Resources

Software: Python, TensorFlow, Torch
Rooms for the lab sessions: Department of Télécommunications

Learning outcomes covered on the course

At the end of this course, the students shall be able to

- understand the main principles of statistical learning theory
- understand the principles and tools of deep learning
- being able to implement deep learning algorithms for classification tasks
- understanding the main tradeoff involved between computational resources, optimization and statistical resources
- understanding practical tricks used for model selection in deep neural networks

Description of the skills acquired at the end of the course

C1.3 Solve the problem using approximation, simulation and experimentation.
C2.1 Have developed an area or discipline related to the basic or engineering sciences.
C6.4 Solve problems using computational thinking.
C6.5 Use all types of data, structured or not, including massive data.
C8.1 Work in a team/collaboration.
C1.5 Mobilise a broad scientific and technical base in a transdisciplinary approach.

3SQ2060 – Advanced topics on cloud computing

Instructors : **Sheng Yang**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

In this course, you will learn basic optimization methods, and most importantly, how to apply them to solve real problems in business.

Quarter number

SG11

Prerequisites (in terms of CS courses)

none

Syllabus

The material is organized in 4 Lectures:

Lecture 1 – Resource Planning
- Introduction to cloud computing
- What is resource planning?
- The newsvendor problem & stochastic resource optimization
- Forecasting demand
- Online learning for resource allocation

Homework 1: Design a forecasting model for the dataset1 and compare with nearest neighbor.

Lecture 2- Load Balancing
- What is Load Balancing?
- Bin packing and best fit
- Join the Shortest Queue
- Lyapunov drift and stability
- Discrete Event Simulation (DES)

Homework 2: Write a DES simulator to allocate tasks to 10 unit capacity servers on the provided dataset2 and compare JSQ versus random allocation.

Lecture 3 - Fairness
- What is fairness?
- Max-min fairness and proportional fairness
- Utility maximization and alpha-fairness
- Most balanced allocation
- Multi-resource fairness

Homework 3: Suppose we must allocate all numbers from 1..365 to three servers, such that number x results in a utility x and needs x/10 resources. Server 1 has capacity 3000, Server 2 has 2500 and Server 3 1500. Is there a max-min fair allocation? And if yes, which is the one?

Lecture 4 – Network Slicing
- What is network slicing?

- Virtual network embedding formulation and applications
- Complexity and Heuristic

Homework 4: Formulate the Virtual Network Embedding problem on dataset3, solve it with Google-OR tools.

Class components (lecture, labs, etc.)

4 lectures with excercises and homework

Grading

The course will be evaluated by means of business reports created by the students. Each student will produce four 1-page business reports, one for each homework. Each report will include an executive summary (3-6lines) that should be a standalone text explaining the 1-pager. The remaining text is up to the student. The report should describe how you solved the homework (math/figures/data should support claims) and be readable by a scientist/manager that is unaware of the current course, and will be evaluated with the following criteria:

- Correctness (3pts)
- Clarity (3pts)
- Conciseness/completeness (3pts)
- Content originality (1pts)

The final grade will be given following ranking and normalization across all students, with a pass given to all who will provide a complete report for all 4 homeworks.

The students are encouraged to start working before class. The material will become available before the end of 2022.

Learning outcomes covered on the course

More specifically, you will:

- Acquire information about how cloud computing infrastructures are optimized
- Learn to perform resource planning and forecasting
- Learn to code Discrete Event Simulators in order to analyse dynamic policies
- Learn to design resource allocation strategies that achieve certain fairness criteria
- Learn to solve resource embedding optimization problems using open source solvers

Description of the skills acquired at the end of the course

C1.2 Use and develop appropriate models, choose the right scale of modelling and relevant simplifying assumptions to address the problem
C1.3 Solve the problem using approximation, simulation and experimentation
C2.1 Have developed an area or discipline related to the basic or engineering sciences.

3SQ2070 – Intelligent Systems

Instructors : **Armelle Wautier**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

The aim of this course is to understand the challenges, levers and obstacles of artificial intelligence, with a focus on trust, ethics and evaluation of intelligent systems.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Deep Learning, Reinforcement learning, Réseaux

Syllabus

AI issues for industry and society
Methodology for designing industrial products integrating AI

Evaluation, homologation and certification of intelligent systems
AI for future networks

Class components (lecture, labs, etc.)

Conferences and discussions with professionals
Experimentation in the form of practical work

Grading

Attendance at lectures and participation to case study are compulsory.
The assessment includes a briefing note.

Resources

Lectures and case studies

Learning outcomes covered on the course

Learning outcomes are :
- identify AI challenges and issues
- being aware of issues of trust, ethics and evaluation of AI
- being aware of good practices in the development of intelligent systems
- being able to understand the limits and potential of AI for future communication networks

Description of the skills acquired at the end of the course

C1 : Analyze, design and build complex systems with scientific, technological, human and economic components
C6 : Be operational, responsible and innovative in the digital world
C9 : Think and act as an ethical, responsible and honest engineer, taking into account the environmental, social and societal dimensions

3SQ2080 – Digital Economy

Instructors : **Raul De Lacerda**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

With the development of new information and communication technologies, the whole world is entering the digital era where digital transformation becomes fundamental to remain competitive in the globalized world. After the invention of steam engines at the end of the 18th century, the appearance of new energy sources at the end of the 19th century and the transport and communication revolution in the 20th century, the integration of communicating systems and connected objects in the industrial chain of products and services represents one of the major challenges of the 21st century and the economy of communication networks the main pillar of this revolution. To respond appropriately to market needs, the management of communication systems must comply with rules which meet cost and efficiency requirements. Therefore, the state plays a very important role in regulatory management to ensure the development of the telecommunications market and the quality of the services provided, as well as the principles of competition and pricing to strike a balance in the relationship between 'Offer and Demand'. This course covers the economic and societal aspects of the communication systems market.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

The teaching will be given in the form of courses :

- Introduction to the regulation of economic activity
- The economic challenges of ICT
    - The rise of broadband
    - Competition and pricing
    - New markets
- The Competition Authority
    - The Authority in France and in Europe
    - Abuse of dominance and impact on the market
    - Merger control in the telecommunications world
- Practical case studies

Class components (lecture, labs, etc.)

This training takes place in the form of lecture courses with compulsory presence.

Grading

Assessment takes the form of a multiple-choice questionnaire (MCQ). Each absence from a lecture will be penalized by 2 points.

Course support, bibliography

D. Battu, "Économie des réseaux de communication", Hermes Science Publishing Ltd 2016.
H. Mazar, "Radio Spectrum Management: Policies, Regulations and Techniques", Wiley 2016.
T.W. Hazlett, "The Political Spectrum", Yale University Press 2017.

Resources

This course will be given by professors from CentraleSupélec and by experts with experience in economic management of new technologies in French State agencies.

Learning outcomes covered on the course

At the end of this course, students will understand the economic challenges of new technologies, as well as the regulatory framework in France and in Europe. This training will allow students to learn the principles and tools that the State has to protect the telecommunication market and stakes in place that require intervention.

Description of the skills acquired at the end of the course

C1. Analyze design and build complex systems with scientific technological human and economic components.
C1.1. Analyze: study a system as a whole the situation as a whole. Identify formulate and analyze a system within a transdisciplinary approach with its scientific economic human dimensions etc.
C2. Develop in-depth skills in an engineering field and a family of professions
C2.2. Import knowledge from other fields or disciplines
C5. Evolve and act in an international intercultural and diverse environment
C5.3. Analyze global and/or local issues internationally and adapt projects or solutions to them
C9. Think and act as an ethical responsible and honest engineer taking into account the environmental social and societal dimensions
C9.2. Analyze and anticipate the possible consequences of organizations and economic models of the structures to which we contribute

3SQ2090 – Computer networks

Instructors : **Sahar Hoteit**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS, FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

The following concepts will be covered in this module:

- Definition of a computer network and layered models (OSI and TCP/IP)
- Physical layer (role, supports, modulation, multiplexing)
- Data link layer (role, error detection and correction, channel access methods)
- Network layer (role, routing, IP addressing, ARP, ICMP and DHCP protocols)
- Transport layer (role, TCP and UDP protocols)
- Application layer (role, DNS, HTTP protocols).

TDs and TPs

- TD1: IP addressing
- TD2: Routing algorithms
- TD3: TCP and DNS protocols
- Lab Session: Configuration of a local network and analysis of Multimedia communication protocols.

Quarter number

SG11

Prerequisites (in terms of CS courses)

SIP (SG1)

Syllabus

- Definition of a computer network and layered models (OSI and TCP/IP)
- Physical layer (role, supports, modulation, multiplexing)
- Data link layer (role, error detection and correction, channel access methods)
- Network layer (role, routing, IP addressing, ARP, ICMP and DHCP protocols)
- Transport layer (role, TCP and UDP protocols)
- Application layer (role, DNS, HTTP protocols).

Class components (lecture, labs, etc.)

Cours/TD/TP
Using the software Wireshark and Packet tracer

Grading

Lab mark+ Final exam

Learning outcomes covered on the course

Understanding the concepts, protocols and mechanisms of the classic computer network (TCP/IP)
Understanding of network concepts underlying the Web.

Description of the skills acquired at the end of the course

- Configuration and administration of network equipment
- Analysis of Multimedia communication protocols

3SQ2100 – Multimedia data compression

Instructors : **Sheng Yang, Frédéric Dufaux**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

Audio-visual and multimedia content is becoming omnipresent nowadays, with applications such as video streaming, video on demand, and social media. This evolution is also made possible by ever more powerful devices, including smartphones and tablets, and better network connectivity. To enable the efficient handling of this multimedia content, effective compression methods are needed. In this module, in a first stage, we will review background theoretical concepts for source coding and compression. After these preliminaries, in a second stage, we will present some of the widely used image and video coding standards. As in most applications, this multimedia content is consumed by human beings, we will also introduce some of the main properties of the human visual system and how they can be exploited in order to reliably assess the visual quality of compressed content.

Quarter number

SG10

Prerequisites (in terms of CS courses)

A background in signal processing, probability theory, and linear algebra is useful

Syllabus

Lecture: Source Coding
Source models (memoryless source, Markov source)
Source coding (uniquely decodable codes, instantaneous codes, prefix codes, Kraft-McMillan inequality, optimal code)
Huffman code, Arithmetic coding, Lemple-Ziv code, Run-length encoding

Lecture: Quantization
Scalar quantization (uniform quantization, non-uniform quantization, Lloyd-Max algorithm)
Vector quantization (k-means or LBG)

Lecture: Transform Coding
Linear transforms, unitary transforms, energy conservation
Karhunen-Loeve Transform (KLT)
Discrete Cosine Transform (DCT)
Optimal bit allocation

Lecture: Predictive Coding
Differential Pulse Code Modulation (DPCM)
Closed loop prediction
Application to video coding: spatial (Intra) and temporal (inter) prediction in video

Lecture: Image and Video Coding Standards
JPEG
JPEG 2000
HEVC (High Efficiency Video Coding)

Lecture: Human Visual System

Main properties of Human Visual System, retina, rods and cones photoreceptors, contrast sensitivity, masking
Subjective quality assessment
Objective (perceptual) quality metrics

Class components (lecture, labs, etc.)

Lectures

Grading

Written exam

Course support, bibliography

T. Cover et J. Thomas, Elements of Information Theory, 2nd ed., Wiley, 2006.
K. Sayood, Introduction to data compression, 2nd ed., Morgan Kaufman, 2005.
A. K. Jain, Fundamentals of Digital Image Processing, Prentice Hall, Englewood Cliffs, 1989
S. Winkler, “Digital Video Quality”, Wiley, 2005
D. Taubman and M. Marcellin, “JPEG 2000: Image Compression Fundamentals, Standards and Practice”, Kluwer Academic Publishers, 2002.
V. Sze, M. Budagavi, G. J. Sullivan, High Efficiency Video Coding (HEVC), Springer, 2014

Resources

Lecturer: Frederic Dufaux (L2S)

Learning outcomes covered on the course

Training students on topics associated with the compression of multimedia content, so that they can apprehend related technical problems and scientific challenges. Source coding, quantization, transform coding, predictive coding, image and video coding standards, human visual system, visual quality assessment

Description of the skills acquired at the end of the course

C1.2 Use and develop appropriate models, choose the right scale of modelling and relevant simplifying assumptions to address the problem
C1.3 Solve the problem using approximation, simulation and experimentation
C2.1 Have developed an area or discipline related to the basic or engineering sciences.

3SQ2110 – Markov models and algorithms for optimisation and learning

Instructors : **Mehrdad Pourmir**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

This module offers a tour in various advanced concepts and tools from signal processing toward digital communications. These include wavelet analysis, adaptive learning of channel parameters, adaptive spectral analysis, filtering and parameter estimation in hidden Markov models, iterative sequence decoding techniques. Practice of algorithm programming and numerical simulation together with supervised sessions of problem solving will facilitate acquisition of essentials.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Background in probability theory and linear algebra at undergraduate level will be useful. Precise statement of mathematical results will be recalled without detailed proofs.

Syllabus

Parts I & II: 7h, parts III & IV: 7h, part V: 4h

I: Adaptive Signal Processing
Principles of adaptive linear mean square analysis
Linear prediction and lattice structure
Projection methods, fast mean square filters
ARMAX models

II: Adaptive Signal Processing
Tutorial & Matlab session
Topics in spectrum estimation, adaptive beam forming, channel equalization and tracking

III: Hidden Markov Models
Models of signals with local dependencies
Combining dynamics and statistics
Reference probability techniques
State estimation of Markov chains and random fields
Monte Carlo optimization techniques

IV: Hidden Markov Models
Tutorial & Matlab session
Topics in Forward-Backward and message-passing decoding, Kalman and particle filtering
V: Wavelet and Time-Frequency Analysis
Lecture and Matlab session
Fundamentals on time-frequency, multiresolution analysis
Construction of discrete wavelet basis
Data compression with wavelets

Class components (lecture, labs, etc.)

Lectures alternate with problem-solving and numerical simulation sessions.

Grading

Student evaluation comprises a theoretical part examination and individual projects (on numerical simulations or technical articles)

Resources

Intensive blackboard lecture/discussion and Matlab simulation

Learning outcomes covered on the course

Ability to identify pertinent statistical models for signal analysis in digital communications. Principles governing the derivation of optimal algorithms and their adaptation to specific constraints.

3SQ2120 – Fundamentals of wireless communications

Instructors : **Sheng Yang**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Wireless communication is becoming an indispensable part of modern society and our everyday life. Yet, engineers are continually facing new challenges due to our evolving needs for higher speed, lower latency, and more reliable connectivity. This course introduces the principles of wireless communications, with a focus on the fundamental information-theoretic limits of communication in an environment with fading and noise. Such principles shall help future engineers understand and solve new problems.

In this course, the student will learn to characterize a wireless channel's capacity and understand the optimal transmission strategies and receiver algorithms, with the help of several lab sessions. To follow this course, the student should have basic notions of digital communications, linear algebra, and probability.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Information Theory (ST4), Communication theory (SG8)

Syllabus

- Lecture 1: Capacity and outage of wireless channels (Lecture + Exercise 3H)
- Lab session 1: "Waterfilling power allocation" (1.5H)
- Lecture 2: Transmission schemes (Lecture + Exercise 3H)
- Lab session 2: "Space-time transmission" (1.5H)
- Lecture 3: Receiver algorithms (Lecture + Exercise 3H)
- Lab session 3: "Receiver implementation" (1.5H)
- Lecture 4: Multi-user communications (Lecture + Exercise 3H)
- Written Exam: 1.5H

Class components (lecture, labs, etc.)

Lectures (12 H, including exercises)
Lab sessions (4.5 H)
Final written exam (1.5 H)

Grading

Lab report (30%) Written exam (70%)

Course support, bibliography

Tse, Viswanath, "Fundamentals of wireless communication"
El Gamal, Kim, "Network information theory"

Resources

Software: Matlab, Python
Rooms for the lab sessions: Department of Telecommunications

Learning outcomes covered on the course

At the end of the course, the student shall be able to
- analyze the capacity of wireless channels
- understand fading, outage, diversity and multiplexing
- understand multi-antenna communications (MIMO)
- apply transmission techniques: beamforming, space-time modulation
- apply receiver designs: linear, non-linear receivers
- understand multi-user communications: uplink-downlink, non-orthogonal access

Description of the skills acquired at the end of the course

C6.7 Understand wireless communication systems
C1.2 Use and develop suitable models, choose the right modeling scale and simplifying hypotheses to deal with the problem
C1.4 Specify, design, build, and validate all or part of a complex system
C2.1 Have deep knowledge of a field or discipline relating to the basic sciences or the engineering sciences

3SQ2130 – Error correcting codes

Instructors : **Antoine Berthet**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The field of channel coding started with Claude Shannon's 1948 landmark paper. Seventy years of efforts and invention have finally produced coding schemes that closely approach Shannon's channel capacity limit. The objective of the course is to provide the students with a general knowledge about the domain and its use at different levels in communications networks. First, we remind students of the basics of the algebraic coding theory for discrete-input memoryless channels. Next, we expound more advanced notions so as to make comprehensible some of the most recent coding schemes proposed in the literature and adopted in modern telecommunications standards, e.g., 4G and 5G cellular systems. Finally, we open up the scope of the course and present important applications involving channel coding such as coded modulations, coded access, network coding, or coding for storage systems.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Solid knowledge of abstract and linear algebra, probability theory, information theory and digital communications.

Syllabus

Part A. Classical channel coding - refreshers

A review of basic notions in channel coding: linear block codes; Hamming, Golay and Reed-Müller codes; linear convolutional codes; Galois fields, general properties, cyclic structure, minimal polynomials, factorization; polynomial codes, cyclic codes, BCH and Reed-Solomon codes; maximum a posteriori probability (MAP) and maximum likelihood decoding (MLD); exact and approximate algorithmic implementation: Viterbi algorithm, forward-backward algorithm, ordered statistic decoding; performance analysis of linear codes under MLD.

Part B. Modern channel coding

Overview of modern channel coding schemes: sparse-graph codes (turbo-like codes, LDPC codes) and polar codes; definition, construction, graphical representation, decoding (loopy belief propagation, list decoding), and performance analysis.

Part C. Opening

Opening on coded modulations (multilevel coding) and recent coding applications beyond per-link channel coding, i.e., how to combine coding with (scheduled or random) access schemes and networking/routing, i.e., network coding for graphical networks and wireless communications networks.

Class components (lecture, labs, etc.)

The teaching includes lectures to recall the fundamental concepts, list of home exercises with solutions for self-training, and optional lab work in MATLAB or C for students who want to implement coding schemes and simulate their performance.

Grading

Final written exam of 1h30 with documents.

Course support, bibliography

[1] COVER, T.M. and THOMAS, J.A., Elements of Information Theory, Wiley, 1991.
[2] EL GAMAL, A. and KIM, Y.-H., Network Information Theory, Cambridge, 2011.
[3] GALLAGER, R.G., Information Theory and Reliable Communication, Wiley, 1968.
[4] MAC WILLIAMS, F.J. and SLOANE, N.J.A., The Theory of Error-Correcting Codes, North Holland, 1977.
[5] RYAN, W.E. and LIN, S., Channel Coding: Classical and Modern, Cambridge, 2009.
[6] VITERBI, A.J. and OMURA, J.K., Principles of Digital Communications and Coding, McGraw Hill, 1979.
[7] YEUNG, R.W., Information Theory and Network Coding, Springer, 2008.

Resources

Lecturer: Antoine O. BERTHET, professor at CentraleSupélec, researcher at Laboratoire des Signaux et Systèmes (L2S)

Learning outcomes covered on the course

At the end of the course, students will be able to:
1) understand the fundamental concepts of the modern channel coding for advanced communication systems;
2) design and model a whole, or parts of a, communication system and assess the communication system performance either analytically or by simulation;
3) determine or optimize the paremeters of communication systems (e.g., choice of operation architecture, information processing algorithms, dimensioning) under physical, energetic, and/or technological constraints.

Description of the skills acquired at the end of the course

C6.7 Understand advanced notions in error-correction coding and applications;
C1.2 Use and develop suitable models, choose the right modeling scale and simplify hypotheses to deal with a problem;
C1.4 Specify, design, build and validate parts of a complex system;
C2.1 Deepen on a field or discipline related to the basic sciences or the engineering sciences;
C2.5 Master the skills of one of the basic engineering professions.

3SQ2140 – Radio access networks

Instructors : **Mohamad Assaad**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS, FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course provides a general description of wireless networks with an emphasis on the main design and modeling challenges in this area. In addition to describing the architecture and basic practical aspects of wireless networks, the course focuses on various multiple access techniques and random access schemes that are used in wireless networks. Tools and theoretical methods that allow optimizing the aforementioned multiple access techniques and thus developing smart transmission schemes will be throughly described. Furthermore, the course presents various emerging aspects that will shape the architecture of future wireless networks (5G and beyond). For instance, topics such as advanced MAC design (based on cross layer and distributed access techniques) for the Internet of Things (IoT) will be covered. Techniques to deal with the high density of future networks will be addressed as well. Finally, theory limitation and implementation of presented schemes will be discussed.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Digital communications, signal processing, optimization theory

Syllabus

- General Introduction to wireless networks (1.5h CM)
    - Use cases and requirements, general introduction to multiple access techniques, modeling and design challenges
- Orthogonal multiple access (6h CM, 3h TD, 6h TP)
    - Introduction to orthogonal multiple access
    - Design of QoS optimal and throughput optimal resource allocation policies
    - Application to CDMA,TDMA and OFDMA (e.g. 4G and 5G)
    - Theory limitation
- Non-orthogonal multiple access (3h CM)
    - Different types of NOMA: principles and comparison
    - Performance analysis and optimization of the network
- Distributed and contention based access (3h CM, 1.5h TD)
    - Standard methods (CSMA, Aloha, etc.)
    - Performance analysis of existing random access methods
    - Performance limits and implementation in large-scale networks (e.g. IoT)

Class components (lecture, labs, etc.)

Organization of the lectures
-General Introduction to wireless networks (1.5h CM)
-Orthogonal multiple access (6h CM, 1.5h TD, 6h TP)
-Non-orthogonal multiple access (3h CM)
-Distributed and contention based access (3h CM, 1.5h TD)

Grading

Final exam (3h): 70% of the final mark
TP: 30% of the final mark

Course support, bibliography

- Jean Walrand, Shyam Parekh, Communication Networks: A Concise Introduction, Second Edition (Synthesis Lectures on Communication Networks) 2nd Edition, 2017
- Erik Dahlman, Stefan Parkvall, Johan Skold, 5G NR: The Next Generation Wireless Access Technology 1st Edition, 2018.
- R. Srikant and Lei Ying, Communication Networks: An Optimization, Control, and Stochastic Networks Perspective, Feb 17, 2014
- Michael Neely, Stochastic Network Optimization with Application to Communication and Queueing Systems, Morgan & Claypool Publishers
- T. Bonald, M. Feuillet, Network Performance Analysis, Wiley, 2011
- D. Levin, Y. Peres, and E. Vilmer. *Markov Chains and Mixing Times*. AMS, 2008
- 5G standard: 3GPP specifications

Resources

Teaching Team: Mohamad Assaad
-Exercices sessions: 25 students per classroom
-Software to use: Matlab

Learning outcomes covered on the course

At the end of the course, the student will be able to:

1- know the architecture and different function of wireless networks
2- model a cellular network with its main functions
3- perform a cellular network planning
4- know the orthogonal and non-orthogonal multiple access techniques and their fundamental performance
5- know the random access methods and the asymptotic performance limit
6- master the modeling techniques of random and multiple access schemes

Description of the skills acquired at the end of the course

C1 : Analyse, design and implement complex systems made up of scientific, technological, social and economic dimensions.
C1.1 : Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem
C1.2 : Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem
C1.3 : Apply problem-solving through approximation, simulation and experimentation. / Solve problems using approximation, simulation and experimentation
C1.4 : Design, detail and corroborate a whole or part of a complex system.
C1.5 : Bring together broad scientific and technical concepts in a core structure contained within the framework of an interdisciplinary approach.
C2 : Acquire and develop broad skills in a scientific or academic field and applied professional areas
C2.1: Thoroughly master a domain or discipline based on the fundamental sciences or the engineering sciences.
C2.3 : Rapidly identify and acquire the new knowledge and skills necessary in applicable / relevant domains, be they technical, economic or others.
C3.2 : Question assumptions and givens. Overcome failure. Take decisions
C9 : Think and act as an accountable ethical professional
C9.2, : Identify, within a given structure, the scope of liability as well as socio-ethical and environmental responsibilities.
C9.4 : Demonstrate rigour and critical thinking in approaching problems from all angles, be they scientific, social or economic.

3SQ2150 – Flow management and quality of service in mobile networks

Instructors : **Salah-Eddine El Ayoubi, Sahar Hoteit**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **15,00**

Description

This course deals with the engineering and dimensioning of wireless networks, including 4G and IoT networks. It details the Quality of Service (QoS) criteria for different services (voice, data, video, IoT) and proposes adequate performance models for each technology/service. We then show how to apply these models for dimensioning the network and implementing an optimal spectrum/radio resource allocation.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Third year course: "Wireless Networks"

Syllabus

- traffic engineering, queuing theory
- dimensioning of wireless networks: 4G, IoT (LoRA/4G IoT)

Grading

Practical work (40%)
Final exam (60%)

Course support, bibliography

- Bouguen, Y., Hardouin, E., & Wolff, F. X. (2012). LTE pour les reseaux 4G. Editions Eyrolles.
- Erik Dahlman, Stefan Parkvall, Johan Skold, 5G NR: The Next Generation Wireless Access Technology 1st Edition, 2018.
- T. Bonald, M. Feuillet, Network Performance Analysis, Wiley, 2011
- 5G standard: 3GPP specifications

Resources

Professors: Salah Eddine Elayoubi
Practical works: Matlab

Learning outcomes covered on the course

Architectures of 4G and 5G networks for different services. Orchestration and management of wireless networks

Description of the skills acquired at the end of the course

performance evaluation
traffic engineering and network dimensioning

3SQ2160 – Sampling theory and compressed sensing

Instructors : **Maxime FERREIRA DA COSTA**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS, FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **15,00**

Description

Sampling is a fundamental task prior to digital processing. It is ubiquitous in system engineering, where input signals are converted from analog to digital, and in data science, where selecting the relevant features drives quality. Covering the mathematical aspects with key principles and applications, this lecture aims to provide a comprehensive overview of the sampling and reconstruction of data and signals from both statistical and practical perspectives.

Starting with the Nyquist-Shannon theorem that demonstrates the exact reconstruction of bandlimited signals, we will walk through the compressed sensing field and show that adapting the sampling strategy for a specific data model makes reconstruction possible at sub-Nyquist rates. Then, we will consider the sampling and reconstruction of more complex data structures, such as matrices and operators. We will finish by considering the numerical distortion produced by data storage over finite-precision numbers and show how an adapted sampling scheme can help tame this issue.

Throughout the lecture, practical emphasis will be given to data science, signal processing, and communication applications.

Prerequisites (in terms of CS courses)

- Linear algebra, Hibert spaces
- Statistics and estimation
- Signal processing
- Signal and communications

Syllabus

- Review of linear algebra (Hilbert spaces and Riesz bases).
- Sampling in translation-invariant spaces.
- Gabor transform and wavelets, applications in image processing.
- Sampling with latent subspace.
- Sampling with a union of subspaces, applications in telecommunications.
- Sampling of signals with finite innovation rates.

Class components (lecture, labs, etc.)

Lectures and lab experiments

Grading

Laboratory Experiment/ Coursework : 50%
Final exam : 50%

Course support, bibliography

- Eldar, Y.C., 2015. *Sampling theory: Beyond bandlimited systems*. Cambridge University Press.
- Mallat, S., 1999. *A wavelet tour of signal processing*. Elsevier.

Resources

- 7.5h lectures
- 6h recitation class
- 1.5h final exam

Learning outcomes covered on the course

1. Identify the advantages and limitations of compressed sensing compared to traditional sampling techniques.
2. Design and implement signal reconstruction algorithms from sampled data within the compressed sensing framework.
3. Understand advanced regularisation and inverse problem-solving techniques applied explicitly to compressed sensing.
4. Perform numerical experiments to evaluate and compare the performance of signal reconstruction algorithms in realistic scenarios.
5. Develop optimised sampling strategies to solve real-world problems using the principles of compressed sensing.

Description of the skills acquired at the end of the course

C1. Analyze, design, and implement complex systems with scientific, technological, human, and economic components.
C2. Develop an in-depth expertise in an engineering domain and within a specific professional field.

3SQ2170 – Information theory and coding

Instructors : **Lionel Husson**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

The aim of this course is to explain the fundamentals of an information transmission and coding chain. After considering the various components of a digital communication chain, and their functions, the course focuses on information theory and the principles of source coding (information compression) and channel coding (information protection).

Quarter number

SG10

Prerequisites (in terms of CS courses)

Learners should be familiar with the basic concepts of probability, random signals and linear algebra.

Syllabus

- Model of a digital communication chain
- Information theory (source entropy, channel capacity)
- Source coding (code properties, decipherable codes, instant codes, Kraft-McMillan inequality, Huffman code, performance)
- Channel and block coding (FEC and ARQ strategies, code properties, block codes, binary linear codes, generator and control matrices, algebraic decoding, Hamming codes, shortened and extended codes, performance)

Class components (lecture, labs, etc.)

Teaching includes lectures, tutorials, experiments and simulations.

Grading

Written examination and laboratory study

Course support, bibliography

J. G. Proakis, "Digital Communications", Fourth Edition, McGraw Hill, 2001.
D. Mac Kay, "Information Theory, Inference and Learning Algorithms", Cambridge University Press, 2005

Resources

Teaching team: Lionel Husson, Jacques Antoine

Learning outcomes covered on the course

At the end of this course, students will be able to:
- understand and describe the components of a digital communication chain and their functions
- Handle information measurements, and the fundamental limits for data transmission
- Construct simple codes using source and channel coding methods in various situations, considering application constraints, and evaluate their performance.

Description of the skills acquired at the end of the course

C1.2 Use and develop appropriate models, choose the right modeling scale and simplifying assumptions to deal with the problem.
C1.3 Solve the problem using approximation, simulation and experimentation

3SQ2500 – Industrial Project

Instructors : **Sheng Yang**
Department : **MENTION INFORMATION AND COMMUNICATION ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) :

Description

The students are required to work, in a group of two or three, on a R&D project during the whole period of the third year. The subject can be proposed by our industrial/academic partners, or by the faculty members of CentraleSupélec. There are three types of projects:
- the CEI: proposed by a company or research lab, supervised by a faculty member
- the immersion project: proposed and supervised by a company or research lab
- the internal project: proposed and supervised by a faculty member

It is a valuable opportunity for the student to work with experts from the industry/academia on a timely subject. The working hours are indicated in the time table (usually, but not uniquely, on Wednesday and Thursday). An academic tutor is assigned to keep track of the general progress of the project.

Quarter number

SD9 SG10 SG11

Prerequisites (in terms of CS courses)

Depending on the project assignment

Syllabus

Depending on the project assignment

Class components (lecture, labs, etc.)

regular meeting, mid-term presentation

Grading

Two intermediate reports
1. Problem formulation, preliminary study, adopted methods, work plan
2. Progress report

Final report
Eventual deliverable (e.g. code, simulation, developed platform)
Defense in front of a jury (supervisor, academic tutor)

Resources

Dedicated time slots every week, computer rooms available

Learning outcomes covered on the course

Problem formulation, bibliography search, computer and scientific tools, scientifique and professional writing and presentation skill, team spirit, autonomy

Description of the skills acquired at the end of the course

C1 Analyser, concevoir et réaliser des systèmes complexes à composantes scientifiques, technologiques, humaines et économiques
C2 Développer une compétence approfondie dans un domaine scientifique ou sectoriel et une famille de métiers
C3.1 Etre proactif, prendre des initiatives, s'impliquer
C3.2 Remettre en cause ses hypothèses de départ, ses certitudes. Surmonter ses échecs
C3.6 Evaluer l'efficacité, la faisabilité et la robustesse des solutions proposées
C3.7 Choisir les solutions et agir de façon pragmatique, en vue d'obtenir des résultats tangibles
C6 Etre à l'aise et innovant dans le monde numérique
C7 Savoir convaincre
C8 Mener un projet, une équipe
C9.3 Agir avec éthique, intégrité et dans le respect d'autrui
C9.4 Faire preuve de rigueur et d'esprit critique dans l'approche des problèmes sous tous les angles, scientifiques, humains et économiques

3SQ3050 – Machine learning, signal and image processing

Instructors : **Simon Leglaive**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **65**
On-site hours (HPE) : **39,00**

Description

Signal and image processing is one of the fundamental but somewhat invisible components of the modern world, without which many technologies we take for granted would not exist: digital telephony, digital radio, television, MP3, WiFi, radar, etc. Recent machine learning techniques seek to exploit the analogy between information processing in biological brains and modeling and statistical inference techniques. These methods are the basis of new technologies that are beginning to reach a significant level of performance and ubiquity, such as techniques for automatic image recognition, voice recognition, assembly line defect detection, medical diagnostic assistance, robot guidance, and autonomous navigation. The many overlaps that exist between signal and image processing and machine learning can be exploited to produce new algorithms of surprising efficiency, and wide applicability, very well suited to the contemporary world of ubiquitous sensors and embedded and connected processing.

Many problems encountered in signal and image processing consist in extracting hidden variables of interest from potentially incomplete and/or noisy observations/measurements. The approaches to be implemented to address this type of problem depend on the nature of the hidden variables of interest (continuous variables, discrete variables, structured signals or images, etc.) and on the availability or not of labeled training data.

Do you want to learn how to extract hidden information from a variety of data types? In this course you will learn how to use mathematical tools to process, analyze and interpret signals/images, as well as machine learning methods to create predictive models from data. Get ready to explore the hidden data in the world around us!

Quarter number

SG10

Prerequisites (in terms of CS courses)

Basic knowledge of statistics, machine learning and signal processing.

Syllabus

- Introduction and applications
- Representation of signals
    * Usual representations (DCT, DFT, wavelets)
    * Non-stationarity, windowing and short-term Fourier transform
    * Sparse representations, compressed sensing, denoising and signal restoration
    * Representation learning (principal component analysis, independent component analysis, non-negative matrix factorization)
- Unsupervised learning
    * Generative modeling
    * Clustering
    * Dimensionality reduction techniques
- Supervised learning
    * Classification
    * Regression
    * Regularization

- Scikit-learn machine learning library (https://scikit-learn.org).

- Applications on various data, for example: analysis, transformation and synthesis of images and audio/speech signals, analysis of temperature measures, analysis of biomedical data to help diagnose diabetes, processing of ECoG (electrocorticography) data for brain-machine interfaces, source separation for non-invasive extraction of fetal electrocardiogram, super resolution for fluorescence microscopy, etc.

Class components (lecture, labs, etc.)

The module is organized in 3-hour lecture sessions alternating theory, exercises and/or practical application in Python, and in 3-hour practical sessions. Each practical session will require preparatory work and the writing of a report.

In autonomy, students will explore a topic of their choice in relation to the course theme. This study will have to integrate scientific and technical components but also human, societal and/or economic ones. It will be presented through a written report and a video presentation.

Grading

Learning outcomes n°1 and 2 will be validated by a final exam in the form of a multiple choice questionnaire (MCQ), representing 1/3 of the final grade.
Learning outcomes n°2 and 3 will be validated by an evaluation of the lab session reports, representing 1/3 of the final grade.
Learning outcome n°4 will be validated by an evaluation of the report and the video presentation of the autonomous study, representing 1/3 of the final grade.

Course support, bibliography

Course materials (presentations, Jupyter notebooks, Python code, and pedagogical activities) will be made available on Edunao.

References:

J. Friedman, T. Hastie, & R. Tibshirani, "The elements of statistical learning" (Vol. 1, No. 10). New York: Springer series in statistics, 2001 (freely available online)
C.M. Bishop, "Pattern Recognition and Machine Learning", Springer, 2006 (freely available online)
M. P. Deisenroth, A. Aldo Faisal, and Cheng Soon Ong, "Mathematics for Machine Learning", Cambridge University Press, 2020 (freely available online)
K. P. Murphy, "Machine Learning, A Probabilistic Perspective", MIT Press, 2012 (available at the library)
S. Foucart and H. Rauhut, "A mathematical introduction to compressive sensing", Birkhauser, 2013
S. Ben-David and S. Shalev-Shwartz, "Understanding Machine Learning: From Theory to Algorithms", Elsevier, 2009 (disponible en ligne gratuitement)

Resources

Teaching team : Clément Elvira, Catherine Soladié, Simon Leglaive, external lecturer.
Software tools : Anaconda (Python package manager).

Learning outcomes covered on the course

Learning outcome #1: Have a general and fundamental knowledge base in machine learning, signal and image processing.
Learning outcome #2: Understand the aspects of problem formalization, modeling and algorithms for data/signal/image processing and analysis.
Learning outcome #3: Design and implement algorithmic solutions to data/signal/image processing and analysis problems.
Learning outcome #4: Conduct and present a study on a new subject integrating scientific and technical components as well as human, societal and/or economic components.

Description of the skills acquired at the end of the course

C1. Analyser, concevoir et réaliser des systèmes complexes à composantes scientifiques, technologiques, humaines et économiques.

C6. Être opérationnel, responsable et innovant dans le monde numérique.

C9. Penser et agir en ingénieur éthique, responsable et intègre en prenant en compte les dimensions environnementales, sociales et sociétales.

3SQ3060 – Ethics, acceptability

Instructors : **Jean-Marc Camelin**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **15**
On-site hours (HPE) : **9,00**

Description

This module addresses the issue of ethics in the company (ethics committee, CSR policy, code of ethics) and responsibility in the engineering profession. It will also address the specificities of the living world, in order to deal with the non-trivial questions and dilemmas posed by the use of digital technology for the living world. For example, how do we approach the question: Is it OK to put sensors on birds to find out more about their habits and habitats, with a view to protecting these species? The answer doesn't seem to be as simple and immediate as yes or no. What is certain is that it's OK to put sensors on birds to find out more about their habits and habitats, with a view to protecting these species. What is certain is that a structured process of reflection is required to reach a decision. Illustrative examples linked to healthcare, the living world as such, but also AI and digital technology in the pharmaceutical industry will be discussed.

Based on concrete cases, the aim is to show that these questions need to be asked and answered, upstream of any action, be it product creation or the launch of scientific studies.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

Introduction to ethics: responsibility, the concept, history, reference texts, the "actions" involved, meaning.
Illustrations of the problem: work (concept, role, suffering at work, emancipation through work), environment (sustainable development, choices to be made, impact), major global issues.
Digital ethics: ethics committee, prerequisites for scientific work.

Class components (lecture, labs, etc.)

Alternance de séances en plénières et d’ateliers, conférences, témoignages de professionnels.

Grading

Oral presentation of a group project (100% of grade and C9).

Resources

Teaching team and outside contributors.

Learning outcomes covered on the course

At the end of this module, students will be able to :
- know how to step back from the professional context to consider the ethical aspect of action
- conduct an ethical reflection on a subject related to Life
- list the ethical steps required to create a product or launch a scientific study

Description of the skills acquired at the end of the course

C9: Think and act as an ethical, responsible engineer with integrity, taking into account environmental, social and societal dimensions.

3SQ3070 – Sensor principles and communication interface circuits

Instructors : **Amor Nafkha**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES)**
Language of instruction : **FRANCAIS, ANGLAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

Sensors are needed to measure (detect) unknown signals and parameters. In particular, sensors are needed to monitor a system and learn more about it. This knowledge will be useful not only for operating or controlling the system, but also for many other purposes, such as process monitoring, experimental modeling, environmental analysis, fault detection and diagnosis, warning generation and monitoring. In general, the output signals of various sensors are analog whereas the inputs/outputs of digital systems are necessarily present in digital form. Consequently, in addition to studying the digital processing part, developing a comprehensive embedded system necessitates learning how to recognize analog phenomena, attempting to retain the majority of the observed phenomena using a signal conditioning block and then convert the analog signal to digital signal using an analog-digital converter before sending it to the digital processing unit using various standard digital communication protocols.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Basic knowledge of analog and digital electronics
Signal processing basics : sampling, correlation, convolution, filtering, Fourier transform

Syllabus

The course is organized in four parts:
- Sensors and fundamental principles
- Conditioning of analog signals
- Analog-to-digital and digital-to-analog converters
- Serial communication protocols (I2C, SPI, UART, ...)

Class components (lecture, labs, etc.)

Learner-centred method (70%)
Teacher-centred method (30%)

Grading

Oral on questions of knowledge (30% of the mark and C6/C9) + report of TPs (40% of the mark and C4/C6/C1) + Read and analyze a technical datasheet (30% of the mark & C4/C2)

Course support, bibliography

1- Wilson, J.S. Sensor Technology Handbook; Elsevier: Amsterdam, The Netherlands, 2004;
2- Das A. Signal Conditioning: An Introduction to Continuous Wave, Communication and Signal Processing, Springer Verlag, Berlin - Heidelberg, 2012;
3- R. V. de Plassche CMOS Integrated Analog-to-Digital and Digital-to-Analog Converters New York; Springer, 2003;
4- Louis E. Frenzel. Handbook of serial communications interfaces: a comprehensive compendium of serial digital input/output (I/O) standards. Newnes, an imprint of Elsevier, 2016;

Resources

Lectures, TDs and TPs sessions with case study
Simulation tools: LTspice, STM32Cube IDE

Learning outcomes covered on the course

The course "Sensors and communication interfaces" will provide students with the necessary knowledge to:
- Analyze, justify and size appropriate components and interfaces for a specific application.
- Model and evaluate ADC/DAC quantification noise and static characteristics
- Understanding serial communication protocols (SPI, I2C, UART, etc.)
- Solve the choice problems arising from specifications (sensor, sensor conditioner, information transport,..)

Description of the skills acquired at the end of the course

C4.1- Define criteria for choosing solutions taking into account all the parameters identified and taking into account the sustainability of solutions in time;
C6 - Be operational, responsible and innovative in the digital world
C9 - Think and act as an ethical engineer, responsible and integrative, taking into account the environmental, social and societal dimensions
Skills may be assessed optionally:
C1.1- Analyze the global behaviour of a complex system (multi-agent, multi-scale, etc.), with its scientific, economic, human, etc., including the identification of factors influencing its behaviour, and the analysis of interactions between components;
C1.2- Enrich models describing phenomena involving several scales or couplings, analyze the sensitivity of a model to its parameters;
C1.4- Prototyper (for example by simulation), realize and validate a system or part of a complex system;
C2.4- Propose a global approach to meet a need for knowledge, integrating state-of-the-art analysis, hypotheses, models, experience (real or digital), interpretation, conclusion;

3SQ3080 – DataVis and Web App to Inform, send feedback, monitor remotely

Instructors : **Gwendal Fouché**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **75**
On-site hours (HPE) : **45,00**

Description

This 75 HEE course covers 4 concepts integrating tech and soft skills.

User-centered design
If we create products for so-called "end-users", these users should be involved during the creation of the product. How can we include them? What are the best practices? What methodology should be used? This is what user-centered design is all about. User-centered design is a design approach in which the needs, expectations and specific characteristics of end-users are taken into account at every stage of the product development process. We will therefore look at the different aspects of this methodology.

Data visualization and graphical user interface
Still on the subject of end-users, how do we get the right information across to them from the data collected? Let us take a healthcare example: patient data has been collected, transmitted and analyzed. Should the same data be provided in the same way to both the patient and the healthcare professional(s)? The answer is probably no. You may have already experienced an incomprehensible medical report. If the data output is not adapted to users, this output is at best useless, at worst a source of annoyance (healthcare professional) or anxiety (patient). It is therefore essential to have data visualization tools that are adapted to users. Users... and their constraints: no more than 30 seconds available for a healthcare professional. How can these constraints be respected? With adapted visuals. In this way, the same data can be visualized differently depending on the person to whom it is addressed. This is the case in healthcare, but also in other application domains. In this section, we will review the main data visualization tools and study their impact on end-users, using case studies and feedback from companies.
Furthermore, with the arrival of massive data, it is becoming impossible to visualize all the data collected. It is therefore necessary to use graphic or interactive tools to translate large quantities of data into understandable and exploitable visuals. This is the objective of data visualization (or datavis), a Data Science discipline, which makes collected data intelligible in order to convey information via representations accessible to all. Data visualization tools are used at various stages of the process, not just by end-users. In particular, they are used extensively in product design and development, to detect emerging trends, or to support decision-making.

Web and mobile applications, AI agents
Coming back to our users, they have now been taken into account right from the start of the design process (user-centered design), and we have beautiful graphics or other representations to provide the relevant information. But on what media should this information be provided? More and more information is captured and/or delivered via digital media, such as the Web and cell phones. With the arrival of AI agents, these digital media are evolving. The aim of this section is to provide you with the know-how you need to quickly design effective user interfaces.

Working in a multidisciplinary environment
Finally, a digital engineer doesn't have the same culture as his or her end-users: a doctor, a farmer, ... or even an engineer from another discipline. This makes it difficult to design digital tools in the fields of Health, Biodiversity or the Environment.
In the course of your studies or professional experience, you have been and will continue to be in contact with professionals from a wide variety of backgrounds. We suggest that you gain a better understanding of these differences, so that you can make the most of them in your future careers.

Quarter number

SG10

Prerequisites (in terms of CS courses)

- Statistics
- Software Engineering

Syllabus

User-centered design and data visualization (75%)

- Introduction to visualization issues: what is necessary in visualization, what is difficult in visualization, and the need for a design process.
- Data representation: how to approach data, what abstraction (type, semantics) to impose to best address the visualization problem?
- Visualization tasks: what do we want to do with the data?
- Displaying information: how to display information to match abstraction and tasks?
- The user in the loop: issues of perception of color, shape and quantity of information
- Imaging visualization: medical, biological, 3D and super-resolution imaging issues
- Visual Analytics: complex systems and infrastructure to support a complete analytic scheme - user-centered design methodology

User interfaces: web application, mobile, AI agent (25%)

- Introduction to JavaScript/AndroidStudio
- Human Machine Interface: how the graphical interface and available interactions support the analysis ?
- Integrating AI technology into interfaces

Class components (lecture, labs, etc.)

Applied course: alternating theoretical input and hands-on practice (50%, 37.5HEE)
Assessment (10%, 7.5HEE)
Group mini-project (40%, 30HEE)

Grading

Personal feedback on a multidisciplinary collaborative experience: 20% of the grade / C5.2
Analysis of a visualization, the issues explored, the techniques used and their relevance, their weaknesses (individual work, 5-10 min oral presentation): 30% of the grade / C1.1, C7.1
Creation of an interactive, mobile or web-based visualization interface, in groups of 3: 50% of the grade / C1.2, C6.2, C6.3

Course support, bibliography

Visualization analysis and design**.** MUNZNER, Tamara. CRC press, 2014.

Resources

Teaching team:

- Gwendal FOUCHÉ
- External contributors

Class size : <= 25

Practical room : 309, Campus de Rennes

Learning outcomes covered on the course

At the end of this course, you will be able to:
- Introduce user-centered design methods.
- Interact in a multidisciplinary environment.
- Select an appropriate representation (type, semantics) for unformatted data.
- Present visualization task classifications.
- Associate a set of simple or complex tasks adapted to a visualization problem.
- Design a visualization taking into account both the objective and the target user.
- Approach complex or specific visualization problems.
- Create a graphical and interactive interface adapted to the problem and the user.

Description of the skills acquired at the end of the course

C1.1 : Analyze: study a system as a whole, the situation as a whole. Identify, formulate and analyze a system within the framework of a transdisciplinary approach, with its scientific, economic, human and other dimensions.
C1.2 : Model: use and develop appropriate models, choose the right modeling scale and simplifying assumptions.
C5.2 : Listen, make oneself understood and work with people from different backgrounds, cultures, codes, training, disciplines, etc.
C6.2 : Design software
C6.3 : Process data
C7.1 : Content: Structure ideas and arguments, summarize (hypotheses, objectives, expected results, approach and value created)

3SQ3090 – Massive MIMO to meet extreme spectral and/or energy efficiencies

Instructors : **Haïfa Jridi**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES)**
Language of instruction : **ANGLAIS, FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

Massive Multiple-Input Multiple-Output (MIMO) is an advanced wireless communication technology that exploits a large number of antennas at both the transmitter and receiver to improve the performance of communication systems.
The fundamental principle of massive MIMO is based on spatial diversity and adapted signal processing. By using a large number of antennas, the system is able to form narrow beams towards each user, which significantly improves signal quality and reduces interference, thus achieving:
- increased spectral efficiency by effectively exploiting the available bandwidth, and therefore considerably increasing the throughput of the system;
- a reduction in energy consumption, by optimizing transmissions to each user.

This course will therefore introduce massive MIMO as a key technology for advanced communication networks such as 5G and beyond. Through two complementary bibliographic projects, we will arrive at the end of this course to understand how this technique allows the growing demand for capacity and energy efficiency in wireless communication systems.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Signal processing

Syllabus

- Basic principles of massive MIMO: spatial diversity, beamforming
- Precoding techniques
- Project 1: Massive MIMO for 5G Mobile broadband applications
- Project 2: Massive MIMO for massive Machine-Type Communication (mMTC)

Class components (lecture, labs, etc.)

Lectures (4h30), supervised projects (6h), project defense and summary (1h30)
The first course sessions will present the context and the basic concepts. Personal work is associated with this part of the course to deepen some specific notions (associated with the type of project to be carried out).
The project sessions that follow will focus on practice through a provided code to understand and analyze in terms of results while exercising critical insight to identify the limits.

Grading

Personal work (20%), Project work and defense (80%)

The individual work that allows to resume the courses given in the first session and prepares the work in the projects will address C2.1.
Understanding the code provided in the projects to present the problem and analyze the relevance of the techniques used will address C1.4.
Teamwork and pooling for the complete and complementary analysis of both projects will validate C8.1.

Course support, bibliography

- Emil Björnson, Jakob Hoydis, Luca Sanguinetti, “Massive MIMO Networks: Spectral, Energy, and Hardware Efficiency,” Foundations and Trends® in Signal Processing, vol. 11, no. 3-4, pp. 154–655, 2017.
- Trinh Van Chien, Emil Björnson, “Massive MIMO Communications,” in 5G Mobile Communications, W. Xiang et al. (eds.), pp. 77-116, Springer, 2017.
- Andrea Pizzo, Luca Sanguinetti, Emil Björnson, “Fundamental limits of energy efficiency in 5G multiple antenna systems,” in Green Communications for Energy-Efficient Wireless Systems and Networks, H. A. Suraweera et al. (eds.), Chapter 9, IET, 2020.

Resources

- Instructor: Haïfa Farès.
- Language of instruction: French, English

Learning outcomes covered on the course

- Understand the fundamentals and benefits of Massive MIMO in wireless communication systems.
- Explore the signal processing techniques specific to massive MIMO.
- Understand the interest of massive MIMO for spectral efficiency and throughput
- Explore techniques for reducing power consumption in massive MIMO systems.

Description of the skills acquired at the end of the course

C1.4 Specify, design, build and validate all or parts of a complex system
C2.1 Deepen on a field or discipline related to the basic sciences or the engineering sciences
C8.1 Building the collective to work as a team

3SQ3140 – IoT infrastructures, data storage and visualization

Instructors : **Amor Nafkha**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES)**
Language of instruction : **ANGLAIS, FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

In order to build IoT end-to-end solutions, this course introduces the key protocols, architectures, software and hardware components from gateway to cloud, and their implementations. Students will learn about cloud and edge computing platforms, IoT gateways, data storage and associated software stacks.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Prerequisites not mandatory but desired:
1- Basic computer and IP addressing skills
2- The basic Linux commands
3- Wireless technologies for IoT
4- Programming languages: Python and C++

Syllabus

Introduction to IoT systems and enabling technologies
IoT architectures
IoT Protocol Stack
IoT components: from gateway to cloud.
IoT data storage
IoT Platforms for Building IoT Projects
Security in IoT

Class components (lecture, labs, etc.)

The main course concepts will be illustrated and implemented in practical works to acquire new skills

Grading

+ 45 min MCQ (50% of the mark and C1/C4/C7)
+ Report of one or two Labs (50% of the mark and C6/C8/C7/C2)

Course support, bibliography

IoT Platforms, Use Cases, Privacy, and Business Models With Hands-on Examples Based on the VICINITY Platform
IoT System Design Project Based Approach
Programmation avec Node.js, Express.js et MongoDB: JavaScript côté serveur

Resources

lectures/ tutorials/Hands-on assignments/self-study

Learning outcomes covered on the course

1- Describe the main software components required in an IoT architecture
2- Develop IoT solutions using open source components and platforms
3- Select appropriate IoT protocols, components and platforms for a specific project
4- Evaluate the connectivity options available to you and select the most appropriate ones

Description of the skills acquired at the end of the course

C1.1: Analyze the global behavior of a complex system (multi-agent, multi-scale, etc.), with its scientific, economic, human, etc., including the identification of factors influencing its behavior, and the analysis of interactions between components
C6 Be operational, responsible and innovative in the digital world
C8 Lead a project, a team
Skills may be assessed optionally:
C2.4: Propose a global approach to meet a need for knowledge, integrating state-of-the-art analysis, hypotheses, models, experience (real or digital), interpretation, conclusion
C4.1: Define criteria for choosing solutions taking into account all the parameters identified (cf. Jalon 2) and taking into account the sustainability of solutions over time
C7.1: Mastering your subject to impose your argument in a situation of competition or contradictory debate.

3SQ3150 – Artificial intelligence and deep learning

Instructors : **Simon Leglaive**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

Recent techniques from the field of artificial intelligence (AI) seek to exploit the analogy between information processing in the living world, particularly in biological brains, and modeling and statistical inference techniques. These methods are at the root of new technologies that are beginning to reach a significant level of performance and ubiquity: automatic image recognition, voice recognition, recommendation systems, writing assistants, medical diagnostic aids, companion robots and autonomous vehicles.

You've heard of neural networks and genetic algorithms, but it all seems a bit obscure? This module will give you a clearer picture, with a hands-on approach to learning.

At the end of this module, you will have acquired a foundation of general and fundamental knowledge, as well as algorithmic skills in the field of AI, enabling you to tackle different application use cases for analyzing data of various kinds.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Basic knowledge of statistics, machine learning and signal processing.

Syllabus

• Bio-inspired algorithms:
- Multi-agent systems
- Genetic algorithms

• Deep learning:
- Multi-layer perceptron
- Convolutional and recurrent neural networks
- Autoencoders
- Generative models

• Mini-project on urban noise pollution monitoring, involving the design and comparison of several algorithmic solutions to a given problem. It will also involve taking a step back and placing the problem in the more general context of eco-acoustics and technologies that can help monitor human and animal activities and biodiversity.

• Autonomous study on one of the following themes identified as priorities in the national AI strategy: embedded artificial intelligence; edge computing; trust, explainability and reliability of algorithms; energy-efficient AI. Some of these themes will also be addressed during the module in guest lectures.

Class components (lecture, labs, etc.)

The pedagogy of this module is practice-oriented:

- Classes dealing with deep learning will take the form of a flipped classroom, with resources (e.g., videos, book chapters) to be studied at home. Classroom sessions will focus on hands-on practice, including a mini-project on monitoring noise pollution in an urban environment.

- Bio-inspired algorithms will be covered in applied courses, alternating theory and practical application.

Grading

Learning outcome #1 will be validated by a final exam in the form of a multiple-choice questionnaire (MCQ), representing 1/3 of the final grade.

Learning outcome #2 will be assessed as part of the mini-project, on the basis of a follow-up note and a video presentation, representing 1/3 of the final grade.

Learning outcome #3 will be validated by an assessment of the report of the conducted study.

Course support, bibliography

Course materials (presentations, Jupyter notebooks, Python code and teaching activities) will be made available on Edunao.

References:

- Aston Zhang, Zachary C. Lipton, Mu Li, Alex J. Smola, "Dive into Deep Learning", 2019.

Interactive book on deep learning, freely available online.

- Ian Goodfellow, Aaron Courville, and Yoshua Bengio, "Deep Learning", MIT Press, 2016.

Deep learning reference book, freely available online.

Resources

Teaching team : Catherine Soladié, Simon Leglaive, external lecturer.

Software tools: Anaconda (Python package manager).

Learning outcomes covered on the course

Learning outcome #1: Have a general and fundamental knowledge of artificial intelligence.

Learning outcome #2: Know how to design, implement and evaluate algorithms from the field of artificial intelligence to solve a given problem.

Learning outcome #3: Conduct and present a study on a new subject integrating not only scientific and technical components, but also human, societal and/or economic ones.

Description of the skills acquired at the end of the course

C2. Développer une compétence approfondie dans un domaine d’ingénieur et dans une famille de métiers

C6. Être opérationnel, responsable et innovant dans le monde numérique

C7. Savoir convaincre

3SQ3160 – Industrial applications, use case study

Instructors : **Catherine Soladie**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

You will be asked to propose and study in detail, in the form of workshops, several specific cases of digital tools for Health, Biodiversity and the Environment. The aim will be to understand the industrial needs of each specific case, the users' issues, and to define the overall processing chain (from sensor to user feedback), specifying, at each stage of the process, how technology choices are made. All this will be based on concrete examples of problems proposed by companies or research laboratories.

Each workshop will focus on a specific theme, which you will study over half or a full day. This module will run throughout the year.

These use cases will also be the subject of examples or in-depth studies in the lessons of the 5 other modules (Raising awareness, Capturing, Transmitting, Understanding, Informing).

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Syllabus

Analysis of 3 to 5 real-life industrial or research cases in the life sciences field:
- Understanding the problem
- Definition of the information processing chain
- Link with teaching modules (Sensors, IoT, Digital Communications, Data Analysis, Signal Processing, DataViz, etc.)
- Choice of one or more solutions for all or part of the pipeline
- Implementation and evaluation of solutions
- Presentation of work (deliverables / defense)

Class components (lecture, labs, etc.)

Presentations by industrialists in the fields covered by the course.
Real-life case studies.

Grading

Some case studies will be the subject of deliverables and/or presentations, which will be assessed. Grading and assessment of skills C1, C3 and C4 will be based on these assessments.

Resources

The teaching team is mainly made up of industrialists from the Health, Biodiversity and Environment sectors.

Learning outcomes covered on the course

At the end of this course, you will be able to :
- Propose a complete pipeline from data capture to user feedback (C1.4)
- Evaluate different solutions (C3.3)
- Choose a technical solution that meets the needs and constraints of users and customers (C1.4, C4.2)
- Arbitrate between several solutions (C4.2)

Description of the skills acquired at the end of the course

C1.4 : Design: specify, produce and validate all or part of a complex system
C3.3 : Concretely implement innovative ideas and commit to decisions, evaluate solutions, move on to industrialization to deliver tangible results.
C4.2: Propose one or more solutions that answer the question reformulated in terms of value creation, and complete the picture by taking into account the impact on other stakeholders and other dimensions. Quantify the value created by these solutions. Arbitrate between possible solutions

3SQ3170 – Data: security, integrity, traceability, law

Instructors : **Yves Louet**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The digitization of information for various processing (learning, statistics, storage, transmission, etc.) affects all economic sectors and in particular those of health and the environment or more generally the living. In order to keep up with developments in information and communication technologies in terms of data protection, the French Data Protection Act of 1978 has evolved and regulates the processing of personal data on European territory under the acronym RGPD "General Regulation on Data Protection”. This regulation, harmonized within the European Union, strengthens the control by citizens of the use that can be made of the data concerning them. Regarding health and the environment, very sensitive digital data is needed to make decisions (often for medical treatment or specific action) and such fundamental questions as how they will be treated, their security, their integrity or their traceability must be based on a precise legal framework for all parties.
This module will therefore address the issues of data & user rights in the context of life, focusing on the context of health and the environment.

Quarter number

SG11

Prerequisites (in terms of CS courses)

This module just requires some basic programming/computer and electronics knowledge to address the technical aspects of this module.

Syllabus

This module contains the following topics. On the regulatory aspects, it will be a question of the RGPD (general regulation on the protection of data), intellectual property and transparency. On the technical side, the issues of equipment vulnerabilities and their security against malicious acts will be addressed. Finally, on practical case studies, focus on health data and the environment will be given.

Class components (lecture, labs, etc.)

This module will take place in different forms: lectures, practical/directed work and case studies.

Grading

This module will be evaluated through on the one hand a report of TP/TD (30% of the mark making it possible to evaluate competence C6.2) and on the other hand through a practical case study (70% of the score used to assess skills C2.2 and C9.2)

Course support, bibliography

Health Data Privacy under the GDPR Big Data Challenges and Regulatory Responses
Edited By Maria Tzanou, 2021

Privacy and Healthcare Data 'Choice of Control' to 'Choice' and 'Control'
By Christina Munns, Subhajit Basu, 2015

Resources

This module includes 30 HEE and 18 HPE.
It will be provided by speakers from the academic world (for regulatory aspects related to data, data security) and the professional world (industry for aspects related to health data, associations for case studies).

Learning outcomes covered on the course

At the end of this module, students will be able to:
- Understand the issue of legislating on the protection of digital data
- Distinguish the convergences between public health law, digital law, GDPR and intellectual protection
- Identify risks and vulnerabilities in the handling of digital data
- Establish the legal specificities of data in the fields of health and the environment

Description of the skills acquired at the end of the course

The learning outcomes at the end of this module are as follows:
C2: Develop in-depth skills in an engineering field and in a family of professions (and more specifically C2.2 regarding multi-sector work and case studies).
C6: Being operational, responsible and innovative in the digital world (and more specifically the skill C6.2)
C9: Thinking and acting as an ethical, responsible and honest engineer taking into account the environmental, social and societal dimensions (and more specifically the skill C9.2 for the case study)

3SQ3180 – Mixed reality and Serious Game to Educate, Involve, Engage

Instructors : **Gwendal Fouché**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **60**
On-site hours (HPE) : **36,00**

Description

This 60HEE course brings together 2 concepts integrating tech and soft skills to address the themes of Raising Awareness, Involving and Engaging.

Serious Game
What if you could save the world from your console or phone?
Games, and video games in particular, are a fascinating medium. You've no doubt already experienced maximum concentration in front of a screen or a board, hours that went by, challenges and limits you've overcome and surpassed. The game does not announce its ideas, it brings them to life. Play does not explain, it implies.
Today, this strength of play shows us that it is possible to go further than mere entertainment: more and more, it enables us to pass on knowledge, know-how, ecological or social awareness... In short, gaming is becoming seriously useful, from industry to the classroom.
In this lesson, you will discover how serious games have helped to transform the transmission of ideas and involvement in a wide range of fields. Based on the analysis of examples such as involving patients in their therapy or raising public awareness of climate issues, you will become the designer of a seriously useful game.

Mixed realities and the metaverse
Beyond physical, tangible reality, new worlds have been emerging over the last few decades: digital content has its own reality. If we can speak of virtual worlds, it's because of the sensory immersion, interactions and new social relationships they offer. With mixed reality having made great strides in recent years, techniques for interacting with virtual environments have been developed, enabling users to perform complex tasks in a rather realistic or pragmatic way. Immersion-related phenomena are also better understood, and the influence of the user's perception of himself and his environment better mastered. All these new methods open the door to numerous possibilities and applications.
After testing and understanding the latest advances in these immersive digital tools, we will look at how they can be used to raise awareness or get people involved. Through concrete examples such as virtual hospitals, therapy for certain phobias or swimming with dolphins, you'll study how luring our senses opens the way to new exchanges between user and system. Mixed reality solutions can be optimized to respond to very concrete problems, particularly in the fields of training, research, health or entertainment. The course can therefore call on professionals in the field to present examples of such applications, as well as the technicalities of this type of project.

Quarter number

SG11

Prerequisites (in terms of CS courses)

- Software Engineering
- Datavis

Syllabus

Serious Game (20%)

- Definition and concepts of Serious Game
- Analysis of existing Serious Games to identify tips and tricks for linking gameplay elements to product objectives
- Design of a Serious Game: identify the audience and the issues to be addressed in order to design the gameplay and the appropriate communication

Mixed reality (50%)

- Mixed reality and immersive technologies: summary of technological developments, from conceptualization in 1965 to modern headsets, introduction to mixed reality concepts, Metaverse and applications.
- The user in the loop: the constraints and freedoms implied by the user and the technology used
- Augmented reality: the balance between real and simulated environments, and related technical issues
- Mixed reality interaction and navigation
- Immersion: study of the phenomena of presence and appropriation of the avatar, ethical issues
- Other modes of perception: haptic feedback, odors, temperatures

Project (30%)

- Group project either based on a serious game, an advanced interaction method or a concrete case study.

Class components (lecture, labs, etc.)

Applied course: alternating theoretical input and classroom practice (45%, 27HEE)
Classroom assessment (15%, 9HEE)
Group mini-projects and face-to-face coaching (40%, 24HEE)

Grading

MCQs: questions on concepts: 20% of mark / C2.1
Practical work assessments (practical work report, serious game pitch): 30% of grade / C2.3, C7.3, C7.4
Group project: oral presentation of approach and techniques used, including ethical reflection (~10min), 3min demo: 50% of grade / C3.1, C7.3, C7.4, C8.4, C9.4

Course support, bibliography

The ultimate display. SUTHERLAND, Ivan E., *et al.* Proceedings of the IFIP Congress. 1965. p. 506-508.
3D user interfaces: theory and practice. LAVIOLA JR, Joseph J., KRUIJFF, Ernst, MCMAHAN, Ryan P., *et al.* Addison-Wesley Professional, 2017.

Resources

Teaching team:
- Gwendal FOUCHÉ
- Catherine SOLADIÉ
- External contributors

Class size: <= 25

Virtual reality head-mounted displays

Software: Unity (free license)

Practical room: 309, Campus de Rennes

Learning outcomes covered on the course

At the end of this course, you will be able to :
- Design a serious game, using game techniques to communicate on concrete issues.

- Present concepts and methods linked to immersive technologies, as well as techniques for implementing such solutions.
- Identify when a problem can be approached in a beneficial way by mixed reality solutions.
- Understand the constraints linked to immersive technologies, the infrastructure and context of the target audience, and the physical and mental limits of the user.

Description of the skills acquired at the end of the course

C2.1: Go deeper into an engineering or scientific discipline
C2.3: Identify and acquire new knowledge and skills independently
C3.1: Observe and allow oneself to criticize the world as it is, doubt, go beyond injunctions, question one's initial hypotheses, allow oneself to learn from one's failures, diagnose
C7.3: On the self: being comfortable and convincing, showing empathy and managing emotions
C7.4: On communication techniques: master spoken, written and body language, and master basic communication techniques
C8.4: Work in project mode, using project management methods appropriate to the situation
C9.4: Act in an inclusive manner with regard to diversity issues such as gender equality, disability, cultural and social diversity, etc.

3SQ3500 – Industrial project

Instructors : **Clement Elvira, Catherine Soladie**
Department : **MENTION NUMERIQUE ET VIVANT (RENNES)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE RENNES**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

This end of study project is a key element of engineering training, it will allow students to place themselves in an industrial context on a long-term study (200 hours).

On an industrial or research problem, this project, carried out in binomial or trinomial, will allow students to apply all their learning outcomes, including:

- teamwork and group dynamics
- project management
- solving complex technical and scientific problems
- written and oral communication

The project can also be a Startup project or a Research project. In this case, the project is not carried out in a student group and the emphasis is placed on autonomy and communication with the different collaborating organizations (replacing teamwork and group dynamics). The other 3 points remain the same.

Quarter number

SD9 SG10 SG11

Prerequisites (in terms of CS courses)

No prerequisites

Syllabus

The subject and the specifications will be specified by the supervisor.

Project progress meetings will be scheduled regularly with the supervisor (s).

Any project must start with a bibliographic search (or "state of the art") to identify existing solutions and seek sources of improvement and innovation to meet the expectations of the project.

Class components (lecture, labs, etc.)

The project will take place on the first 3 sequences of the third year, with the following distribution for timetabled hours:

- SD9: 24h
- SG10: 48h
- SG11: 72h

This is supplemented by work outside the scheduled time slots to reach the 200-hour target.

It will be supervised by one or more teacher-researchers; in the case of a study linked to an industrial company, regular monitoring will be organized with the company.

Grading

At the end of the SD9 and SG10 sequences, a defense and an intermediate report will allow the progress of the work to be assessed.

The final evaluation of the project will be carried out at the end of the SG11 sequence by a defense before a jury, a report and the deliverables.

Resources

The projects are divided into teams (binomial or trinomial, depending on the study), or alone in the case of a startup or research project, with one or more supervisors.

Students will have available the hardware and software environments necessary to carry out this project.

Supervision: teacher-researchers and industrial stakeholders

Learning outcomes covered on the course

The aim of the project is to develop the autonomy and responsibility of the pupils, to create a group dynamic and the spirit of collective work and of course to put into practice the lessons received.

It should allow students to assert their know-how and to consider their skills.

Like the internship in a company that will follow, the project constitutes one of the last links in the transition between studies and first job.

Description of the skills acquired at the end of the course

C1.5 Mobilize a broad scientific and technical base within the framework of a transdisciplinary approach.
C3.5 Propose new solutions / tools either out of step or in continuous progress
C3.6 Evaluate the effectiveness, feasibility and robustness of the proposed solutions
C3.8 Knowing how to design, produce and move on to industrialization
C6.2 Practice collaborative design through product design and prototyping tools (CAD, 3D printer, etc.).
C7.1 Convince on the merits. Be clear about the objectives and expected results. Be rigorous on the assumptions and the approach. Structure your ideas and your arguments. Highlight the value created.
C8 Lead a project and work as a team
C9.4 Demonstrate rigor and critical thinking in approaching problems from all angles, scientific, human and economic

3SQ4010 – Introductory and industrial seminars

Instructors : **Philippe Benabes**
Department : **MENTION ELECTRONIC ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **32**
On-site hours (HPE) : **19,50**

Description

The purpose of these seminars is to present the mention and meet our partners in order to discover the problems of engineers in the field of electronics.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

Introduction of the mention: 1h30
Economy of electronics: 6h
Partners specific activities presentation: 6*1h30 (the final program is not yet established but the partners approached are :
Airbus, Safran, Thales, SLB, ST microelectronics, Nokia)
Company visit : 3h

Class components (lecture, labs, etc.)

the conferences and partnairs presentations will leave a large part to the interactions between the students and the speakers.

Grading

The module is validated (pass/fail) by the presence of the students in the different activities and a small MCQ of a few questions organized at the end of each 3 hour slot.
The module is validated from 60% of correct answers to the various MCQs.

From 2 absences or non-validation of MCQs, additional synthesis work will be required.

The C2 skill will be validated from the moment the module is validated.

Course support, bibliography

none

Resources

This introduction will be done through general conferences :
* introduction of mention,
economics of electronics,
specific conferences with our partners,
and a partner visit

Learning outcomes covered on the course

The objective of these seminars is to draw a portrait of the state of the art and the perspectives of modern electronics (More Moore, More-than-Moore and Beyond CMOS) and microwaves from a point technical, integrative (new design predicates) and economical.

Description of the skills acquired at the end of the course

C2: Develop an in-depth skill in a scientific or sectoral domain and a family of trades

C2.1 Identify and quickly acquire new knowledge and skills necessary in the relevant fields, whether technical, economic or other
Create knowledge, in a scientific approach

3SQ4020 – Architecture of Analog Circuits

Instructors : **Emilie Avignon-Meseldzija**
Department : **MENTION ELECTRONIC ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

The purpose of this course is to present the most widely udes analog architectures used in electronics. The architectures seen in this course start from one-transistor based circuits (common source, common drain, common gate) to OTA with one or two stages, bangap reference voltages, transmission gate, multiplier, adder/subtractor, comparators. Finally, classical systems composed of circuits blocks of more of ten transistors will be studied (Gm-C filters, PLL, Simple ADC).
To facilitate the understanding of the concepts behind this course and to get some training for the job of electronics designer, the study of each architecture will be illustrated with LtSpice simulation with more or less realistic models.
Finally a confirmed analog electronics designer from Elsys Design will come to share her experience in a 1h30 seminar.

Quarter number

SG10

Prerequisites (in terms of CS courses)

It is required to complete SD9 SCOC, or have a M1 in Electronics equivalent of Master E3A from Université Paris Saclay or a M1 from a partner school.

Syllabus

CM1/TD1 : The basics circuits (architecture, small signal analysis, properties) with one and 2 transistors : common source, common drain, common gate + telescopic cascode + voltage reference
CM2/TD2 : circuits with several transistors (1) : current mirror, diff pair, One stage OTA, Miller OTA.
CM3/TD3 : circuits with several transistors (2) + switches : transmission gate, multiplier, adder/substractor, comparator
CM4/TD4 : Gm-C Filters, Gyrators
CM5/TD5 : PLL and Frequency Synthesizers

Séminaire ELSYS DESIGN : a confirmed analog electronics designer from Elsys Design will come to share her experience in a 1h30 seminar.

Practical work: 2 subjects will be proposed with different kind of applications. For each subject tere will be a step of dimensioning/simulation to be achieved on LtSpice with real models of components from the market or with real models of transistors.

Class components (lecture, labs, etc.)

Lectures, tutorials, practical works

Grading

A written exam for 70% and practical works for 30% of the evaluation

C6 will be evaluated based on project/practical work where results must be obtained with electronics simulators. A mark greated than 12/20 will allow to validate this compentence.
Competences C1 and C2 will be evaluated based on all activities. A mark greater than 10/20 will be required for the exam and a mark greater than 12/20 will be required for the project/practical work.

Course support, bibliography

T. C. Carusone, D. A. Johns, and K. W. Martin, Analog Integrated Circuit Design, 2nd ed. Danvers, MA: John Wiley & Sons, Inc., 2012.
B. Razavi, Design of Analog CMOS Integrated Circuits, McGraw Hill, 2003.
R. Jacob Baker, CMOS Circuit Design, Layout, and Simulation, 3rd ed., John Wiley & Sons, Inc., IEEE Press, 2010.

Resources

This course is based on :
- 15h00 of lecture (CM) and tutorials (TD)
- A company (ELSYS DESIGN) de 1h30
- 9h00 of practical work with LtSpice and/or PCB

Learning outcomes covered on the course

At the end of this course the students will be able to:
- Propose an analog architecture depending of the application
- Predict some order of magnitude and trade-off for the most widely used architecture
- Understand and calculate circuits composed of tenth of transistors

Description of the skills acquired at the end of the course

C1 : Analyse, design and build complex systems with scientific, technological, human and economic components

C2 : Develop in-depth skills in a scientific or sectoral field and a family of professions

C6 : Be at ease and innovative in the digital world

3SQ4030 – Advanced digital systems

Instructors : **Caroline Lelandais Perrault**
Department : **MENTION ELECTRONIC ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **60**
On-site hours (HPE) : **36,00**

Description

This course introduces and trains students in the methodology of designing complex digital and logic systems, from functional specification to logic synthesis on FPGAs. The first part of the course, consisting of lectures and tutorials, prepares students for the second part of the module, in which they study how to design a detailed architecture in the form of a block diagram assembling standard blocks sized to the optimum, starting from a specification describing an algorithm. The second part of the module is centered around a project to be carried out based on a specification. The project aims to obtain a complete realization running on an FPGA board. By way of introduction, a presentation by an industrial partner will set out the context and methodology for the development of FPGA-based embedded digital systems. Once the specifications have been presented, students will be asked to propose a block diagram architecture. Then a succession of lectures/tutorial sessions will enable them to learn the VHDL language and build the basic blocks required for the project, using the ModelSim tool. Finally, during the project sessions, students will have to implement their solution, carry out unitary tests, validate it in simulation, and finally, on an FPGA board.

Quarter number

SG10

Prerequisites (in terms of CS courses)

This course is directly linked to the "Embedded systems architecture and design" course taught in SD9 of the SCOC major.
In addition, it is a real plus to have taken the SPI course "Electronic Systems" (two occurrences in SG1 and two occurrences in SG3) and the elective course "Digital Systems and Processor Architecture" (SG6).

Syllabus

Course outline:

Fundamentals of logic and digital architectures (6 HPE) :
- Lecture (3h): Basic digital concepts on sequencing (Finite State Machine), multi-domain clocking and synchronization, complex systems (data paths/sequencer).
- Tutorial (3h): Architecture and operation of the accumulator and a FIR filter.

Contextualization of the project in an industrial setting (3 HPE):

- Lecture (3h): Presentation by Airbus on the context and methodology of designing a system on FPGA in a company, and presentation of the project to be carried out.

Course, Tutorials, and preliminary studies for the project (12 HPE) :
- Lecture/Tutorial (3h): Introduction to VHDL, process, hierarchy, and testbench / first implementation
- Lecture/Tutorial (3h): Packages and arithmetic operations / signed number and fixed-point calculations
- Lecture/Tutorial (3h): Simple sequential functions / frequency divider
- Lecture/Tutorial (3h): State machines

Project development (15 HPE)

- Project (3h): Project architecture design

- Project (10h30): Implementation, unitary testing and validation
- Exam (1h30): Oral presentation of project and results.

Class components (lecture, labs, etc.)

After an introductory lecture, the module is made up exclusively of Lecture/Tutorial and project sessions, to encourage the acquisition of skills through learning. For all these practical sessions, students work in small groups. Each student will have a Linux or Windows workstation installed with design software and a DE10-lite FPGA board.

Grading

Assessment will be based on the work carried out during the practical sessions and the project. Session work, the quality of the design, the performance of the systems produced, and the clarity of the presentation of the architectures and results will be graded. Unjustified absences will have an impact on the grade.

Resources

Students will get hands-on experience with professional digital design tools such as ModelSim and Quartus. Two rooms at CETIC are equipped with Linux/Windows workstations and FPGA boards. The tools can also be installed on students' personal machines if they have Windows and Linux systems.

Learning outcomes covered on the course

On completion of this course, students will be able to design a complex digital system based on a specification and high-level modeling. They will be able to build a block diagram architecture that implements the required algorithm, design the various blocks in VHDL, test them in simulation, interpret the results, understand the causes of any failures encountered, and propose solutions to these problems. They will have mastered an FPGA-based digital system development tool.

Description of the skills acquired at the end of the course

The work carried out by the students will enable them to acquire the skills to specify, design and analyze a logic and digital system using a hardware description language. These skills will be acquired throughout the module on a situational basis. Skill C1 will be acquired and validated during Tutorial sessions. Skill C2 will be acquired and validated during the project. Skill C6 will be acquired and validated through the implementation and proper use of software, as well as through the proper writing of the VHDL language.

3SQ4040 – Smart and integrated antennas

Instructors : **Andrea Cozza**
Department : **MENTION ELECTRONIC ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course presents an overview of the main types of antennas used in wireless communications, with particular attention to the technologies used in 5G, satellite communications, portable communicating systems, and IoT devices.

The course consists of three fundamental units

- antenna basics
- adaptive array antennas and beamforming
- integrated and miniature antennas

The educational approach aims to highlight the building blocks found in technological solutions used in communicating objects, their main features and limitations.

Quarter number

SG10

Prerequisites (in terms of CS courses)

SD9 SCOC

Syllabus

Introduction to antennas

- CM1 (1h30) Wire antennas
- CM2 (1h30) Patch antennas
- CM3 (1h30) Aperture antennas
- TD1 (1h30) Wireless transmission scenarios

Beamforming, smart antennas

- CM4 (1h30) Uniform linear arrays
- TD2 (1h30) Phased arrays
- TL1 (1h30) Array antenna measurements
- CM5 (1h30) Adaptive beamforming
- TD3 (1h30) Interference control
- TL2 (3h00) Smart antenna (beamforming) for 5G mobile phones (simulations with CST Microwave Studio)

Small & integrated antennas

- CM6 (1h30) Size-reduction techniques
- CM7 (1h30) Planar compact antennas, physical limitations
- TL3 (1h30) Miniature PIFA antennas
- CM8 (1h30) RFIDs
- TL4 (1h30) RFID tag back-scattering

Class components (lecture, labs, etc.)

The course is organized into three parts in order to simplify the assimilation of the concepts introduced. For each part, tutorial classes present the technologies introduced during the lessons for a specific application. The main focus will be on the practical differences between the application scenarios discussed: these cover a wide range of cases, mirroring the vast number of configurations in which antennas are used in wireless communications.

To this end, approximately half of the classes will be tutorial and laboratory classes. Software tools such as CST Microwave Studio and Matlab will make it possible to explore complex scenarios.

Grading

The evaluation will be carried out using two different approaches: 1) through three multiple-choice quiz (MCQ) tests, one at the end of each part, 2) answering questions proposed at each tutorial/laboratory classes, as a homework. The MCQ are meant to test the understanding of the antenna technologies and their related applications. The questions will cover both concepts introduced during the lectures as well as those explored during tutorial and laboratory classes.

Course support, bibliography

- Lecture slides, solutions to tutorial classes
- C.A. Balanis, "Antenna theory : analysis and design", Wiley & Sons

Resources

Lecturers : Andrea Cozza, Dominique Lecointe
Number of students in each tutorial class : 35
Software tools : Microwave Studio (CST), Matlab.
Laboratory activities: array antenna tests.

Learning outcomes covered on the course

At the end of this course, the students will know how to

- identify which type of antenna is best suited to a given application
- design antenna arrays, and make them adaptable to changing conditions thanks to beamforming techniques
- understand the intrinsic limitations of integrated antennas, and the leading technologies used in practice

Description of the skills acquired at the end of the course

The following competencies will be acquired throughout the course

C1 : Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2 : Develop in-depth skills in an engineering field and a family of professions

3SQ4050 – Radio propagation

Instructors : **Andrea Cozza**
Department : **MENTION ELECTRONIC ENGINEERING (PARIS-SACLAY)**
Language of instruction : **ANGLAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **32**
On-site hours (HPE) : **19,50**

Description

This course introduces key concepts and tools for understanding and modeling wave propagation through configurations found in real-life applications, where the presence of obstacles (buildings, etc.) results in complex propagation conditions. The course is built around three broad topics

- wireless power transmission, under far- and near-field conditions (NFC, RFID)
- interaction between waves and obstacles, in urban & indoor environments, as well as close to the human body
- multi-path propagation and the techniques used in mitigating its adverse effects (antenna diversity, MIMO)

which cover the main transmission scenarios found in wireless communications. The tools and concepts introduced make it possible to understand the challenges inherent in wireless communications in realistic situations, from indoor local area networks to wearable connected objects. The course will present the main technological solutions developed to ensure robust and efficient transmissions through these complex environments, such as antenna diversity and MIMO systems, essential concepts in the new generation of technologies related to 5G and IoT applications.

Quarter number

SG11

Prerequisites (in terms of CS courses)

SD9 SCOC

Syllabus

Wireless transmissions in free space

- CM1 (1h30) Link budgets, path losses
- TD1 (1h30) Maximum coverage range
- CM2 (1h30) Near-field transmissions

From free space to complex media

- CM3 (1h30) Interaction with structures: scattering and diffraction
- TD2 (1h30) Two-path propagation & fading
- TL1 (1h30) Slow & fast fading
- TL2 (1h30) Attenuation through walls (simulations with CST Microwave Studio)
- CM4 (1h30) On-body propagation

Multi-path propagation and multi-antenna techniques

- CM5 (1h30) Multi-path propagation

- TD3 (1h30) Propagation macro-models for urban/indoor settings
- CM6 (1h30) Multi-antenna techniques
- TD4 (1h30) Robust reception: antenna diversity
- TL3 (1h30) Multi-path propagation, diversity & MIMO (reverberation chamber)

Class components (lecture, labs, etc.)

The approach pursued in this course aims to be pragmatic and has two complementary objectives: to understand the reasons for the variability of the transmission properties according to the nature of the medium, while highlighting their impact on application scenarios. To this end, half of the sessions will be tutorial and laboratory classes, aimed at applying the concepts introduced during the lectures. Software tools such as CST Microwave Studio and Matlab will enable exploring complex scenarios.

Grading

The evaluation will be carried out using two different approaches: 1) through three multiple-choice quiz (MCQ) tests, one at the end of each major topic, 2) answering questions proposed at each tutorial/laboratory classes, as a homework.
The MCQ are meant to test the understanding of propagation phenomena and their impact on concrete application cases. The questions will cover both concepts introduced during the lectures as well as those explored during tutorial and laboratory classes.

Course support, bibliography

- Lecture slides, solutions to tutorials
- J.D. Parsons, “The mobile radio propagation channel”, Wiley & Sons
- K.L. Du, M.N.S Swamy, “Wireless communication systems”, Cambridge University Press

Resources

Lecturers : Andrea Cozza, Dominique Lecointe
Number of students in each tutorial class : 35
Software tools : Microwave Studio (CST), Matlab
Laboratory activities: propagation around obstacles, multipath propagation.

Learning outcomes covered on the course

At the end of this course, students will be able to

- understand the reasons for the high variability found in wireless transmissions
- predict the risk for adverse conditions in real-life applications
- design multi-antenna solutions in order to ensure reliable transmissions in multi-path media

Description of the skills acquired at the end of the course

The following competencies will be acquired throughout the course

C1 : Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2 : Develop in-depth skills in an engineering field and a family of professions

3SQ4060 – Components for analog electronics

Instructors : **Emilie Avignon-Meseldzija**
Department : **MENTION ELECTRONIC ENGINEERING (PARIS-SACLAY)**
Language of instruction :
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **15**
On-site hours (HPE) : **9,00**

Description

The purpose of this course is to present the main components of analog electronics: the diode (PN junction), the CMOS transistors, the operational amplifier (AOP), passive components (resistors, capacitors, inductors).
The approach is focused on the designer needs. It means that the physics is explained superficially (PN junction and transistors) just to understand the functioning and the equations commonly used by the designers.
Concerning the operational amplifier and the passive components, after some quick reminders, the limitations will be focused: noise, gain-bandwidth product, parasitic effects, frequency range…to provide to the future designer the ability to select the suitable component for an application.

Quarter number

SG10

Prerequisites (in terms of CS courses)

There is no specific prerequisite as this course introduces some basics.

Syllabus

This course is based on lectures (CM) and exercises (TD) for a total of 9h00.

CM1/TD1: introduction to the cross sectional view of integrated circuits: the PN junction + understand the behavior of the transistor in the different functioning mode based on the cross sectional view.
CM2/TD2: MOS Transistors: quadratic equations, small signal models of the transistors, study method of a circuit based on 1 transistor: bias point calculation then small signal analysis. Understanding of frequency limitations.
CM3/TD3 : Reminders on opamp and passive components. Limitations of opamp (gain-bandwidth product and noise) and passive components. Introduction to datasheet analysis for selecting a suitable component.

Class components (lecture, labs, etc.)

This course is based on lectures and tutorials

Grading

A 45 minutes written exam

Resources

This course is based on lectures (CM) and exercises (TD) for a total of 9h00.

Learning outcomes covered on the course

At the end of this course the students will be able to :
- Understand/calculate a simple circuit with diodes (PN junction)
- Understand/calculate circuits with only one transistor NMOS/PMOS
- Understand/calculate circuits based on operational amplifiers
- Predict limitations and suitable configuration depending on applications (RF transistors vs Power transistors, gain/bandwidth product…)

Description of the skills acquired at the end of the course

C1 : Analyse, design and build complex systems with scientific, technological, human and economic components
C2 : Develop in-depth skills in a scientific or sectoral field and a family of professions

3SQ4070 – Fundamentals of electromagnetism

Instructors : **Dominique Lecointe**
Department : **MENTION ELECTRONIC ENGINEERING (PARIS-SACLAY)**
Language of instruction :
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **15**
On-site hours (HPE) : **9,00**

Description

Maxwell's theory plays an important role in the design of embedded electronic systems. Electromagnetic waves are used in wireless communications, such as Wi-Fi, Bluetooth, NFC, 4G/5G, etc., to transmit data and signals between electronic devices. Antennas are used to transmit and receive electromagnetic signals, which enables wireless communication between electronic devices, sensing the environment of our electronic systems. In addition to all these useful applications, electromagnetism is one of the bases of electromagnetic compatibility, ie the electromagnetic pollution generated by our electronic equipment or disturbing their operation. These applications will be developed in several courses of the mention.
The objective of this course is to lay the foundations of Maxwell's theory. These bases will then be used in several courses of the mention.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

Part 1

Applications and frequencies
Equations: Maxwell, constitutive equations, transition relation, time domain, frequency domain
Types of problems, assumptions and main results

Part 2

Plane wave: properties, polarization
Reflection of a plane wave on a perfectly conductive plane
Reflection and refraction of a plane wave on a perfect dielectric

Part 3

Guided propagation and line theory
Telegraphers' equations and solution analysis
Adaptation
Standing wave ratio

Class components (lecture, labs, etc.)

Courses and exercises using a digital tool of electromagnetism

Grading

Personal written work to be submitted at the end of the course

Course support, bibliography

Presentation slides on edunao
Book of course 1A: Radiation and propagation

Resources

• Software tools and number of licenses required: MWS software. Educational license obtained from the supplier.
• Classrooms: Computer room

Learning outcomes covered on the course

At the end of this lesson, the student will be able to:
- put into equations a realistic problem by choosing more or less complex models.
- judge the relevance of the models and their limitations.
- choose a resolution methodology including modern simulation tools.
- master the structures of electromagnetic waves propagating in a given medium.
- master the systems allowing the propagation of an electromagnetic signal.

These achievements will be used in several courses of the ELEN mention
These different learning outcomes make it possible to validate skills C1 and C2

Description of the skills acquired at the end of the course

C1: analyze, design and build complex systems with scientific, technological, human and societal components
C2: develop in-depth skills in an engineering field and in a family of professions
More specifically, the C1 and C2 skills acquired at the end of this course will be a contribution to the level of methods for solving problems of electromagnetism.

3SQ4120 – Integrated Electronics (INTELECT)

Instructors : **Pietro Maris Ferreira**
Department : **MENTION ELECTRONIC ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Integrated electronics, also known as microchips, are everywhere as a key technology in many modern devices, including computers, smartphones, and industrial equipment. They are made up of many transistors and passive devices that are etched onto a millimeter-squared piece of Silicon. The XXI century shortage of integrated circuits is a result of a combination of factors that have been exacerbated by the COVID-19 pandemic as:

· Strong demand for electronic devices related to remote work and learning, as well as devices for entertainment during lockdowns.
· Disruption of global supply chains , as foundries were forced to close or operate at reduced capacity, which slowed down production.
Countries that could design and produce their own integrated circuits are said to have technological sovereignty. This can also contribute to economic sovereignty, by reducing the amount of money spent on importing technology and by increasing the capability to deliver technological solutions to the society needs.

Quarter number

SG11

Prerequisites (in terms of CS courses)

For students from CentraleSupelec, it is required to complete the 3rd year minor ELEN from SCOC major.

Syllabus

1. CM1 : Integrated Electronics – Context, Challenges, and Industry 4.0
2. TP1. Hands on Virtuoso Cadence
3. CM2 : Integrated Electronics Manufacturing: from the physics of semiconductors to the economy of integrated electronics through modern industrial integration processes, presenté par XFAB France
4. CM3: Integrated Electronics Manufacturing: from the physics of semiconductors to the economy of integrated electronics through modern industrial integration processes, presenté par XFAB France
5. CM4 : Modeling, characterization, and simulation of transistors for modern industrial technologies presenté par XFAB France
6. CM5 : Modeling, characterization, and simulation of transistors for modern industrial technologies presenté par XFAB France
7. CM6 : Design of Experiments : from physical dataset generation to Circuit and System design equations.
8. TP2 : Practice of the Design of Experiments using a single stage amplifier.
9. TP3 : Physical Design of a Ring Oscillator using CADENCE (DRC, LVS, EXT)
10. TP4 : Physical Design of a Ring Oscillator using CADENCE (DRC, LVS, EXT)
11. CM7 : Passive Integrated Circuits (R, L, C, K, TL, …)
12. CM8 : Design for Reliability and physical phenomena (PVT, MC, Corners, Aging, Faults)
13. TP5 : Practice of Design for Reliability for a Ring Oscillator
14. TP6-7-8 : IC Design Practice on CADENCE (évaluation)

Class components (lecture, labs, etc.)

Industrial seminars, classic courses, exercise courses and lab courses. Balance between theory and practice, knowledge, and know-how.

Grading

a) Execution of 2 MCQs on the subject of industrial seminars to validate C2
b) “IC Design” work exam prepared in advance (requires 20 HEE) with a practical/experimental validation session which represents 100% of the final mark (validation of C1 and C6).
c) Final exam includes a series of theoretical questions. It is performed in April before leaving for the internship. This exam allows you to make up for only C1 in the criteria : C1 in milestone 3 (score greater than 12) or milestone 2 (score greater than 7). In the case of non-validation of C2 and or C6, it cannot be caught up by this evaluation (ie skill not evaluated/not acquired).

Course support, bibliography

Razavi, B. (2005). Design of Analog CMOS Integrated Circuits (2nd ed.). Mc Graw Hill.
Jespers, P. (2010). *The gm/ID Methodology, a sizing tool for low-voltage analog CMOS Circuits*. In Springer US. Springer US. https://doi.org/10.1007/978-0-387-47101-3
Carusone, T. C., Johns, D. A., & Martin, K. W. (2012). *Analog Integrated Circuit Design* (2nd ed.). John Wiley \& Sons, Inc.
Debroux, J.-F. (2020). *Top-Down method at work in analog IC design*. Open Access.
Ferreira, P. M. (2023). *Polycopié Electronique Intégré*. Open Access

Resources

This course proposes a teaching equilibrium between theory and exercises. It has also practical courses using Linux workstations and a professional CAD software: Virtuoso CADENCE.

Learning outcomes covered on the course

During Integrated Electronics course, students will learn about
1. how to design, meet performance trade-offs, draw layout, and fabrication of integrated circuits, using electronic design automation (EDA) tools.
2. fabrication and design of microelectronic from industry point of view, including semiconductors, transistors, circuits, and systems.
3. the requirements of integrated electronics in various fields, such as Internet of Things, airspace electronics, biomedical instruments, and industrial automation.

Description of the skills acquired at the end of the course

a) Validation of skill C1: The “IC Design” work consists of a set of theoretical questions. This makes it possible to validate the C1 skill in milestone 3 (average greater than 12) or milestone 2 (average greater than 7)
b) Validation of skill C2: The industrial seminars will deepen the field of engineering sciences in the integrated electronics sector, especially through the know-how and interpersonal skills illustrated by the temporary workers. Participation in industrial seminars with the answer to the MCQ (one per seminar) proposed by the individual contractors makes it possible to validate the C2 skill in milestone 3 (average greater than 12) or milestone 2 (average greater than 7)
c) Validation of competence C6: Laboratory activities with CAD software require competence in data processing and the numerical solution of problems (eg design of experiments). Participation in the labs validates competency C6 in milestone 2. The “IC Design” work includes a set of questions to be verified by simulation. This makes it possible to validate the C6 skill in milestone 3 (average greater than 10).

3SQ4140 – Precision, Instrumentation, Measurements (PRIME)

Instructors : **Jerome Juillard**
Department : **MENTION ELECTRONIC ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This course focuses on the analysis and optimization of the error budget of a measurement or acquisition chain, from the fundamental principles to their practical implementation in the form of an electronic implementation. The focus is on :
- the nature of errors (noise, offsets, parasites, influence quantities, drifts), their physical origin and their mathematical representation (spectrum, variances, etc.)
- their impact on the metrological performance and their analysis, in connection with the various stages of the measurement chain (transducers, conditioners, amplifiers, references, digitisation).
- measurement and acquisition techniques (synchronous detection, chopping, auto-zero, resonant measurement, etc.), as well as calibration techniques that can be used to avoid errors, at least in part.
This course should allow students to make the link between a system-level vision of the measurement chain, approached during the lectures, and a component vision, approached during the tutorials and practical work. It is thus not only aimed at future designers, but also at future project engineers or system architects.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Modeling (transfer functions), Electronics (opamps, ADCs), Control (closed-loop control), Signal Processing (power spectral density)

Syllabus

This course consists of:
- 18 hours of lectures (CM) and exercises (TD) or practical work (TP):
  - CM 1 & 2: error budget, metrological characteristics, noise and drift.
  - CM 3 & 4: transducers, conditioners, amplifiers.
  - TD 1 & 2 (pen and paper): analysis and optimisation of a measurement chain 1
  - CM 5 & 6: instrumentation methods and techniques.
  - CM 7 & 8 : methods and techniques of precision electronics.
  - TP 1 & 2 (LTSpice): analysis and optimisation of a measurement chain 2
- 4h30 of conferences (ASYGN: integrated precision electronics, SLB: precision and extreme environments, APIX: embedded chromatography, from concept to product)

Class components (lecture, labs, etc.)

Lectures 9h
Labs/Tutorials 9h
+ conferences

For students who have already taken the CIMEMS modulus in 2A or an equivalent modulus, the opportunity is offered to design, build and test electronics associated with a MEMS sensor in project mode.

Grading

50% lab evaluation + 50% final exam (MCQ)
or
50% project report + 50% project defense.

Course support, bibliography

Acquisition de données - 3ème édition, G. Asch
Introduction to Instrumentation and Measurements - 3rd Edition, R.B. Northrop
The Art of Electronics - 3rd Edition, P. Horowitz, W. Hill

Resources

Coventor, LTSpice, Cadence, Simulink, Simplorer softwares

Learning outcomes covered on the course

At the end of this course students should be able to:
- Determine an error budget for a measurement or instrumentation application
- Know the advantages and limitations of common transducers, conditioners, amplifiers, etc.
- Dimension and choose the elements of an acquisition chain to reach given specifications

Description of the skills acquired at the end of the course

C1/C2

3SQ4150 – Electromagnetic Compatibility

Instructors : **Dominique Lecointe**
Department : **MENTION ELECTRONIC ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

IOT systems, like all electronic systems, must meet the requirements arising from electromagnetic compatibility problems. The communicating aspect of these systems also requires compliance with the requirements related to radio compatibility. In addition, the protection of these systems against voluntary electromagnetic attack will be a necessity.
The challenges addressed by this course will be :

- economic issues (the solutions to the future system must be compatible with the constraints linked to regulations and the competitive environment)
- environmental issues (taking into account the pollution generated by our systems and equipment is today in the foreground; this course deals with electromagnetic pollution)
- societal issues (the vulnerability of electronic and communicating systems highlights the fragility of our modern societies; moreover, the public, workers are more and more sensitive to the problems of exposure of people to electromagnetic waves)

Quarter number

SG11

Prerequisites (in terms of CS courses)

Electromagnetism : radiation and antennas, free propagation and plane wave, guided propagation and line theory

Syllabus

- Electromagnetic compatibility and human exposure
- Radio compatibility
- Co-existence of communicating systems
- Electronic warfare
- Conference by the National Agency of Frequencies

Class components (lecture, labs, etc.)

1 conference of 1h30, 9 lessons of 1h30, 2 TD of 1h30 and 1 TP of 3h00

Grading

The evaluation will focus on four criteria:
- a presentation on a theme proposed at the beginning of the course.
- the methodology for constructing the presentation and the associated bibliography
- the relevance of the questions asked during the presentations of the other students
- the TP report
Competency C1 is validated if the student has the average on the assessment.
The C2 competency is validated if the student has the average in the TP report
The C7 competency is validated if the student has the average in the methodology and bibliography

Course support, bibliography

Electromagnetic Compatibility by Pierre Degauque and Joel Hamelin

Resources

- teaching staff : Dominique Lecointe, Raul de Lacerda
- conference by the National Agency of Frequencies
- specific room for TP

Learning outcomes covered on the course

At the end of this course, the student will be made aware of the need to take into account the electromagnetic compatibility and exposure problems from the design phase of the future system.
In a constrained economic environment, the student will be able to:

- to put into equations a realistic problem by the choice of more or less complex models.
- judge the relevance of the models and their limitations.
- choose a resolution methodology including modern simulation tools
- validate its solution in compliance with the regulations

Description of the skills acquired at the end of the course

C1.1 : Examine problems in their entirety and beyond their immediate parameters. Identify, formulate and analyse the scientific, economic and human dimensions of a problem
C1.2 : Develop and use appropriate models, choosing the correct modelling scale and simplifying assumptions when addressing a problem
C2.3 : Rapidly identify and acquire the new knowledge and skills necessary in applicable / relevant domains, be they technical, economic or others.
C7.1 : Persuade at core value level; to be clear about objectives and expected results. To apply rigour when it comes to assumptions and structured undertakings, and in doing so. Structure and problematise the ideas themselves. Highlight the added value

3SQ4160 – Digital processing implementation

Instructors : **Erwan Libessart**
Department : **MENTION ELECTRONIC ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **45**
On-site hours (HPE) : **27,00**

Description

This course introduces and trains the methodology of implementing digital processing architecture on FPGA and is divided into two parts. The course begins with a presentation and introduction to an industrial software for the implementation of an embedded system on FPGA (Vivado). This will provide the opportunity to implement a complete embedded system and see the interaction between hardware and software. The second part consists of a project to size and implement a neural network on FPGA in order to recognize numbers on images from a camera. This will be an opportunity to improve their knowledge of the VHDL language discussed in previous courses.

Quarter number

SG11

Prerequisites (in terms of CS courses)

This course is a logical continuation of the ELEN-marked Architecture and Design of embedded Systems (SD9) courses in the SCOC dominant and Advanced Digital Electronics (SG10) courses in the ELEN Master.

Syllabus

In the first part of the course, students will discover and use Vivado professional software, using Xilinx's official tutorial as a support, to implement early examples of complex digital processing systems.
In the second part, students will design and size a CNN-like neural network for digit recognition on an image before coding the VHDL description of the associated electronic architecture for on-board testing.

Class components (lecture, labs, etc.)

The whole course will be run in project mode, where the students' autonomy will be encouraged, all under the supervision of the reference teachers.

Grading

Both parts of the course will be evaluated individually. These evaluations will take the form of reports on the work carried out at the end of each part. Each rating will count for 50% of the final score.

Resources

Students will be required to practice on professional software (Vivado, Quartus, Modelsim) on workstations that will be made available to them. FPGA development boards will be available to test their architectures.

Learning outcomes covered on the course

At the end of this course, students are able to use industrial software to build a functional digital processing system consisting of a processor coupled to a hardware accelerator. They will also be able to optimize this accelerator by designing an efficient architecture, based on a specification.

Description of the skills acquired at the end of the course

The competency assessed in this course is the C2 competency: “Develop in-depth skills in an engineering field and in a family of professions”. This evaluation will be done via practical works.

3SQ4500 – Industrial Project

Instructors : **Andrea Cozza**
Department : **MENTION ELECTRONIC ENGINEERING (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

Three types of projects are proposed: CEI projects, partner projects, and internal projects. The CEI projects result from a contract signed between the school and an industrialist who presents a subject of study. One or two teachers from the SCOC "dominante" supervises the students. The sponsoring companies of the mention give the partner projects. The company itself provides supervision. The internal project concerns a subject given by a teacher-researcher of the dominant. Typically, the project can involve a research activity of the teacher-researchers own research.

Quarter number

SD9 SG10 SG11

Prerequisites (in terms of CS courses)

none

Grading

Defense and a report are required at mid-term and at the end of the project.

Resources

Depending on the project's nature, the supervision will be done by the industrial partner or teacher-researchers. Students will have access to the material available in the teaching department. For CEIs, if specific equipment is needed, the industrial partner will lend the equipment to the school for the project's duration.

Learning outcomes covered on the course

The project's objective is to confront the students with a set of specifications close to an industrial or academic issue. The students will have to exploit the skills and knowledge acquired so far. They will also have to develop their autonomy and spirit of initiative.

Description of the skills acquired at the end of the course

The following competencies will be acquired throughout the course

C1 : Analyze, design, and build complex systems with scientific, technological, human, and economic components
C2 : Develop in-depth skills in an engineering field and a family of professions
C3 : Act, undertake, innovate in a scientific and technological environment.
C7 : Know how to convince
C8 : C8 Lead a project, a team

BIOTECHNOLOGY AND ENVIRONMENTAL ENGINEERING MAJOR (VSE)

3VS1010 – Concept of the living, biology, microbiology, genomics

Instructors : **Filipa Lopes**
Department : **DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **65**
On-site hours (HPE) : **39,00**

Description

The general principles that define the living organism, presented as a complex system, will be addressed through a multi-scale approach, from cell to population: macromolecule, intracellular organelle, cell, population of cells (microorganisms in suspension and immobilized in the form of biofilms).

The general objective of this course is to introduce the concepts of life sciences necessary to better understand it, to be able to exploit it in various applications in industry (production of biomolecules), in the environment (water and waste treatment) and to better control it in a health context.

The principles will be addressed through a multidisciplinary approach at the interfaces of biology/microbiology, biochemistry, physics and bioprocesses in order to obtain a global and integrated vision of living organisms.

Quarter number

SD9

Prerequisites (in terms of CS courses)

none

Syllabus

- Theory of evolution
- The bricks of life: macromolecules, enzymes and enzyme kinetics
- The cell: structure and functions, prokaryotic/eukaryotic cell
- Cell machinery: 1) from gene to protein, 2) metabolism and its regulation
- Diversity of life
- Biofilms (formation, structure and impacts)
- Virus (structure/replication mechanisms)
- Cell culture (principles and applications)
- Synthetic biology (concepts and applications).

Class components (lecture, labs, etc.)

The general principles will be illustrated with realistic examples and applications and addressed in the form of lectures. Students will also attend to a conference on synthetic biology and two laboratory practicals (Microbial culture and enzyme kinetics).

Grading

Written examination (1.5h) and reports of the laboratory practicals.

Course support, bibliography

- Presentations of the various speakers.
- Books :

Madigan, M. (2007). Brock Biologie des microorganismes ;
Meyer, A., Deiana, J., & Bernard, A. (2004). Cours de microbiologie avec problèmes et exercices corrigés-2e édition.

Resources

Teaching team: C. Bernard (Dr, Inserm), F. Lopes (Pr, Centralesupélec), B Taidi (Pr, Centralesupélec), K. Maouche (MCF, U. Paris Diderot)

Learning outcomes covered on the course

- Define the different building blocks of life: proteins, sugars, lipids and nucleic acids.
- Describe the method of protein coding : genetic code, DNA, RNA, replication, transcription and translation.
- Explain the mechanisms of enzymatic reactions and describe the different kinetics.
- Identify different metabolic pathways and their relation to different process (bioethanol production, nitrogen removal from wastewater, ...).
- Identify different mechanisms of metabolic regulation.
- Estimate the growth rate of a microbial population and discuss the factors impacting it.
- Define biofilm and list the associated impacts.
- Identify different ways of operating bioreactors.

Description of the skills acquired at the end of the course

C1, C2

3VS1030 – Biostatistics

Instructors : **Arthur Tenenhaus**
Department : **DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

This course presents the statistical tools needed to answer the various questions raised by the analysis of biomedical data.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Statistics and Machine Learning

Syllabus

- Univariate approach and multiple testing (Bonferonni, False Discovery Rate…)
- General linear model (ANOVA / ANCOVA) and mixed effect models.
- Generalized Linear Models (Logistic regression, Poisson regression, etc.)
- Principal Component Analysis and Clustering Hiérarchique

A large part of the concepts presented during this course will be implemented during practical work (using the R software)

Grading

Homework assignment

3VS1040 – Modeling and numerical methods applied to living organisms

Instructors : **Véronique Le Chevalier, Emmanuel Odic**
Department : **DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **50**
On-site hours (HPE) : **30,00**

Description

The objective is to assimilate the modeling approach through examples of different types of models from various fields of application (epidemiology, genetics, ecology, medicine, plant biology, bioprocesses, etc.) and to master the various associated mathematical methods. These methods are generic, but the specificities of living processes (complexity, variability, redundancy, etc.) impose certain precautions with which the students will become familiar thanks to a "red thread" modeling project that will allow them to put them into practice.

Quarter number

SD9

Prerequisites (in terms of CS courses)

Course 1A Modeling (Model Representations and analysis): basic notions for the analysis of dynamic systems, parametric estimation, uncertainty and sensitivity analysis.
Course 1A Statistics and Machine Learning: Parameter estimation.

Syllabus

- Initiation and practice of the R language
- Pre-requisite session for M2 PBA students (and FreeMoov, optional)
- General principles and specificities of modeling for the life sciences applications
- 1st part: two paradigms of models : (1) systems of non-linear ordinary differential equations, with illustration on bioreactor models, and numerical schemes for their resolution; (2) cell automata with illustration on cell proliferation and displacement models
- 2nd part: Methods for analysis and model evaluation : (1) Uncertainty analysis (type A or B, Shannon's maximum entropy principle) and sensitivity analysis (SRC indices, variance combination method, Sobol indices based on variance decomposition); (2) Parametric estimation of non-linear dynamic models, model selection (penalized criteria, cross-validation), structural and practical identifiability, reminders on optimization methods for the minimization of the criteria resulting from the estimation problem (continuous optimization and description of two heuristic algorithms from biology : genetic algorithm and particle swarm optimization).
- 3rd part: Transition from a deterministic model to a stochastic model, Gillespie's algorithm.

Class components (lecture, labs, etc.)

Sessions generally include a lecture part, a TD (usually with analytical parts on paper and computer exercises for direct application of the concepts seen in class on simple examples), and a time for application on the "red thread" project.
This project is chosen at the beginning of the course and consists of the analysis of an article from the scientific literature: the student must implement the model(s) presented and apply all the methods seen in class, as it progresses. He must also find and present a 2nd paper presenting either another model of the same biological system or a review of different modeling approaches in his chosen field. The subjects of the projects are of varying difficulty which allows an adjustment of the level of ambition according to the initial level of the student.

Grading

- report and oral presentation of the project (50%)
- 1h30 written exam, with only one authorized document: one sheet of paper, both sides handwritten (50%)

Course support, bibliography

A. Saltelli, Sensitivy analysis in practice

Resources

- Team of teachers
- Course handbook
- practicals

- Project subjects
- Some videos

Learning outcomes covered on the course

At the end of this course, students will be able to:
- for a given system or phenomenon, propose an adequate model in terms of descriptive variables, time/space scales, type (deterministic/stochastic, continuous/discrete, etc.) with respect to the targeted objectives
- to implement the methodological loop of analysis and evaluation of the models developped, taking into account the specificities of living systems, among which we can cite a low standardization of models, extremely complex phenomena, systems that are little or partially observable, large variability.

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C2. Develop in-depth competence in a scientific or sectoral field and a family of professions

3VS1050 – Physiological bases of Neurosciences

Instructors : **Christophe Bernard, Emmanuel Odic**
Department : **DOMINANTE - VIVANT, SANTÉ, ENVIRONNEMENT**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **42**
On-site hours (HPE) : **25,00**

Description

Understanding how the brain works (and how it malfunctions) is the ultimate frontier for humans. The goal of the course is to give you the basics of the field through an engineering approach: (i) the molecular basis of the genesis of a bit of information by a neuron, (ii) the propagation and transfer of this information to other neurons, and (iii) the integration of signals. These basics will allow you to understand the basics of memory (iv), and how these functions are affected in diseases (v). You will see that Neuroscience calls upon all sciences, especially those of the general engineer.

Quarter number

SG11

Prerequisites (in terms of CS courses)

No prerequisites

Class components (lecture, labs, etc.)

Lecture course

Grading

Written production requiring reflection and mobilization of course knowledge

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C2. Develop in-depth competence in a scientific or sectoral field and a family of professions
C9. Act as a responsible professional. Think and act ethically.

3VS2010 – Process Engineering - Reactors, Mass and heat transfer

Instructors : **Filipa Lopes, Victor Pozzobon**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Today's chemical reactors are particularly complex, as they involve increasingly demanding unit operations (downsizing, reduction of dead volumes, intensification of transfers). The increasingly refined characterization of these tools is therefore a real need for the industry. To answer these questions, engineers have various tools at their disposal, both experimental and numerical. The most emblematic methods are: Residence Time Distribution (RTD) determination, for the experimental part, and Computational Fluid Dynamics (CFD), for the digital part. Without claiming to make students experts in the field, the aim of this teaching is to train managers who are aware of the problems associated with non-ideal flows. Thus, through three main sequences, students will explore models of non-ideal reactors and then learn how to make (in practical work) and analyze a RTD. Then, they will manipulate computational fluid mechanics tools. Finally, they will apply them to three major fields of reactor engineering: turbulence (intensification of transfers), natural convection (which is a challenge to master, particularly in the food industry) and porous media (increase in fluid/catalyst contacts). Thus, once in the company, our engineers will be able to interact in an enlightened and relevant way with the expert members of their future teams.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Heat and mass transfer

Syllabus

Part 1: Experimental Approach to Real Reactors (Arnaud Buch)
- Modeling of Single Phase flows (reactors) - simple models / sophisticated models & DTS Residence Time Distribution (integrated 9h TD course)
- Experimental determination of the RTD and application (1 TP of 3h)

Part 2: Turbulent flows in reactors (Victor Pozzobon)- Numerical modelling of turbulent flows (1h recalls)
- Applications of CFD on case studies simulating reactors (integrated TD course, 11h)

Part 3: Numerical modelling of flows in natural convection and porous media (Denis Flick)
- Natural convection course / Porous medium
- Digital case studies

Class components (lecture, labs, etc.)

This teaching is divided into three parts. First, models of chemical reactors are presented in a step-by-step fashion (simple models, then more complex ones). The notion of Residence Time Distribution, essential for the engineer, is then introduced. It is first approached from a theoretical point of view (course and TD) and then practical with a TP. In a second time, another tool for the engineer is approached, the numerical simulation (through the Comsol software according to an integrated course/TD modality). It is with this tool that three major fields of reactor engineering are explored: turbulence, natural convection and porous media.

Grading

Written final exam evaluating the 3 parts of the teaching.

Course support, bibliography

PDFs of the different courses.

Bibliography
Distribution des temps de séjour et efficacité des réacteurs chimiques, Techniques de l'ingénieur, J4014, Jean-Léon Houzelot
Chassaing, P. (2000). Mécanique des fluides.
Chassaing, P. (2000). Turbulence en mécanique des fluides.

Resources

RTD pratical equipment, computer room

Learning outcomes covered on the course

At the end of this teaching, the student will be able to :

1) Choose the reactor models adapted to a situation
2) Propose a method for the implementation of an experimental RTD
3) Handling a numerical fluid dynamics tool (Comsol)
4) Analyze situations of turbulence, natural convection and flows in porous media

Description of the skills acquired at the end of the course

- C1

3VS2020 – Process Engineering - Process Energy optimisation

Instructors : **Hervé Duval, Filipa Lopes**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **24,00**

Description

The conversion of resources (renewable or not) for the production of goods and services (including energy) meets the sustainable development requirement if the processes implemented are energy-optimized.
This course aims at understanding the needs and opportunities of energy optimization of processes, as well as exploring and using the tools dedicated to this energy optimization.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

After an introduction specifying the challenges of energy optimization for industrial sectors, two scales are explored: the (bio)process (methanization, fuel production) and the industrial plateform (biorefinery).
The courses are delivered by experts directly involved in energy optimisation within their industrial structures, and consists in lectures, followed by case studies.

Class components (lecture, labs, etc.)

The course module is organized in lectures (10 hrs), to introduce knowledge and methodological tools, which will be then applied through case studies (10 hrs). It is completed by a visit to an agricultural biogas production unit (2 hrs).

Grading

Continuous assessment, by group: 2 case studies.

Course support, bibliography

- Feidt M. *Thermodynamique et optimisation énergétique des systèmes et procédés*, Tec & Doc Lavoisier, 2016, 480 p.
- Caposciutti, G.; Baccioli, A.; Ferrari, L.; Desideri, U. *Biogas from Anaerobic Digestion: Power Generation or Biomethane Production?*, Energies, 2020, 13, 743, 15 p.
- Zoughaib A. Méthode du pincement, Techniques de l'ingénieur, 2019, 13 p.
- Trably, E. ; Christophe G. ; Latrille E., Larroche C. *Production de biohydrogène - Voie fermentaire sombre*, Techniques de l'ingénieur, 2018, 32 p.
- Escudie R. ; Cresson R. *Méthanisation de la biomasse*, Techniques de l'ingénieur, 2017, 23 p.

- Ptasinski, K.J. *Efficiency of biomass energy: An exergy approach to biofuels, power, and biorefineries*, John Wiley & Sons, 2015, 784 p.

Resources

The teaching staff is exclusively composed of experts from industry, working daily on the issues of process energy optimization:

- EDF,
- Air Liquide,
- IFPEN,
- Roquette Group.

The licensed software will be made available to the students by the industrialists.

Learning outcomes covered on the course

At the end of this course, students will be able to:

- Understand the challenges of reducing industrial energy consumption,
- To use energy optimization tools for industrial production units.

Description of the skills acquired at the end of the course

C1. Analyse, design, and implement complex systems made up of scientific, technological, social, and economic dimensions
C2. Acquire and develop broad skills in a scientific or academic field and applied professional areas

3VS2030 – Process Engineering - Mass and heat transfer

Instructors : **Patrick Perre, Filipa Lopes**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **24**
On-site hours (HPE) : **12,00**

Description

Coupled heat and mass transfers occur in many configurations, both in nature (climate, soil-plant-atmosphere system) and in the engineering field (building heating, air conditioning, industrial processes, etc.).

Depending on the physical state of the water, material transfers take place through different mechanisms: vapour and bound water diffusion, capillary migration, Darcy's law ... In addition, during the three stages mentioned above, changes of state occur, which lead to heat transfers. To understand the transfers, back to equilibrium, one must first understand the equilibria, which will be studied in detail, starting with the notions of humid air and capillary pressure.

The simulation of water variations in the biomass therefore requires modelling involving a coupling between matter and heat transfer.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

1. Reminder of the notions of balance
    - Phase diagram of water (pure material)
    - Humid air
    - Capillary water
    - Equilibrium moisture content
2. Configurations out of equilibrium
    - Transfers in a homogeneous medium
    - Conservation equation
    - Transfer in a porous medium
3. Coupled transfers
    - Wet-bulb temperature
    - Description and analysis of convective drying

Class components (lecture, labs, etc.)

The course module is organized in lectures (10,5 h). From the fundamental principles, several practical situations (for everyday life) are studied to develop models suitable for simulate the dynamics of coupled transfers.

Grading

1,5-hour individual written exam

Course support, bibliography

- R Byron Bird, Warren E Stewart, and Edwin N Lightfoot. *Transport phenomena*. New York, 1960.
- A. Houberechts. *La thermodynamique technique, tables et diagrammes thermodynamiques*. Bruxelles, 4ème edition, 1989.
- F.P. Incropera and D.P. DeWitt. *Fundamentals of Heat and Mass Transfer*. New York, 1990.
- R. Keey. *Introduction to Industrial Drying Operations*. Pergamon Press, 1978.
- O Krischer and K Kr• oll. *Die wissenschaftlichen Grundlagen der Trocknungstechnik*. Berlin/G• ottingen/Heidelberg, 1956.
- P. Perré. *Le séchage du bois, dans Le bois, matériau d'ingénierie*, p. 201-287. ARBOLOR, 1994.
- P. Perré, editor. *Fundamentals of Wood Drying*. European COST and ARBOLOR, 2007.
- E. Sanchez-Palencia and A. Zaoui. Homogenization techniques for composite media. In *Homogenization techniques for composite media*, volume 272, 1987.
- D.A. Van Meel. *Adiabatic convection batch drying with recirculation of air*. Chemical Engineering Science, 9(1) :36{44, 1958.
- S. Whitaker. Simultaneous heat, mass, and momentum transfer in porous media: a theory of drying. In *Advances in heat transfer*, volume 13, pages 119-203. Elsevier, 1977.

Resources

Teaching staff: Patrick PERRÉ / Julien COLIN
Software: R, Excel
Bibliography, Abaci

Learning outcomes covered on the course

At the end of this course, students will be able to:

- Understand the equilibriul states, in the air or in a porous medium,
- Identify the different mass transfer mechanisms (diffusion / convection) working in a given configuration and the potential coupling between heat and mass transfer,
- Simplify a seemingly complicated problem, where several transfer phenomena coexist, by taking into account only the main ones,
- Formalize phenomena into equations through elemental heat and mass balances.

Description of the skills acquired at the end of the course

C1, C2

3VS2040 – Process Engineering - Process Control

Instructors : **Filipa Lopes, Sihem Tebbani**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

Biotechnologies and, more particularly, the study of bioprocesses are at the heart of current concerns with environmental and ecological requirements in the context of sustainable development. The applications of bioprocesses are very various: environmental remediation, biofuels, cosmetics, food, etc.

One of the major objectives when designing and operating a bioprocess is to ensure its optimal operation, i.,e. maximizing its yield while minimizing operating costs.

The objective of this course is to acquire the basic skills to understand, analyze, and design the monitoring and the control of bioprocesses, and more specifically, the culture of microorganisms in bioreactors.

The concepts presented in this course are general and can be applied to the control of chemical processes.

Quarter number

SG10

Prerequisites (in terms of CS courses)

There is no specific prerequisites.

Syllabus

The course consists of three parts.
First, the modeling of a bioreactor culture is detailed, and mathematical models capable of describing the macroscopic behavior of the bioprocess are developed .
The second part will focus on presenting the software sensor design strategy to reconstruct biological variables not available online. These sensors will also be used to monitor the system.
Finally, the third part of the course will build on the concepts presented in the two previous parts in order to design efficient control strategies to maintain the system in an optimal operating point.
Several examples of culture of microorganisms (bacteria, microalgae and yeasts) in bioreactors will be presented. These examples will be a common thread throughout the course (modeling, estimation, optimization and control).
More specifically, the course will be structured as follows:

- Mathematical macroscopic modeling: The mathematical macroscopic modeling of the bioprocess is expressed according to a formalism that will be used throughout the course. (1h30 lecture).
- Estimation/monitoring (software sensors). (1h30 lecture).
- Tutorial: modeling and estimation of bioprocesses. (1h30)
- Optimal operating conditions : Determination of optimal operating conditions, either experimentally or numerically. The general concepts of optimization are presented. (1h30 CM)
- Control of bioprocesses : The most common control strategies will be presented, from classical methods (PID for example) to advanced techniques adapted for complex, non-linear and uncertain systems. (3h lecture)
- Tutorial: bioprocess optimization and control. (3h)

Class components (lecture, labs, etc.)

This course consists of lectures followed by tutorials.
A software will be used in tutorials (MATLAB or Python), on concrete examples of bioprocesses with environmental applications.

Grading

Project-based assessment (in pairs).

Course support, bibliography

- Slides.
- Current Developments in Biotechnology and Bioengineering, éditeurs Ch. Larroche, M. Sanroma´n, G. Du, A. Pandey. Elsevier, 2017.
- On-line Estimation and Adaptive Control of Bioreactors, G. Bastin, D. Dochain, Elsevier, 1990.
- Automatic Control of Bioprocesses, éditeur D. Dochain. Wiley-ISTE, 2008.
- CO2 Biofixation by Microalgae: Modelling, estimation and Control, S. Tebbani, F. Lopes, R. Filali, D. Dumur, D. Pareau, Wiley-ISTE, 2014. Disponible également en Français.
- Monitoring and Control of Fermenters, G. Montague, IChemE, 1997.
- Process Dynamics and Control, D.E. Seborg, T.F. Edgar, D.A. Mellichamp, John Wiley, 2nd edition, 2004.

Resources

Teachers: Sihem Tebbani, Didier Dumur.
Size of the tutorial group: 35 students
Software tools: Matlab.

Learning outcomes covered on the course

At the end of this course, the student will be able to :

- Analyze the operation of a bioprocess, model its behavior in a macroscopic way and propose solutions to improve its performance and efficiency.
- Propose and design software sensors for bioprocess monitoring, taking into account technical and economic criteria (feasibility, accuracy of measurements and associated costs).
- Understand and analyze the existing control laws implemented for the operation of a bioprocess
- Propose and design control strategies to obtain an optimal operation of the bioprocess, for different applications (food, biochemistry, environment, production of pharmaceutical products, animal cell culture...).
- Apply the acquired skills to the supervision and control of chemical processes.

Description of the skills acquired at the end of the course

- Analyse, design and build complex systems with scientific, technological, human and economic components (C1).
- Develop in-depth skills in an engineering field and a family of professions (C2).

3VS2050 – Bioprocess Engineering - Upstream

Instructors : **Filipa Lopes, Julien Colin**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **10**
On-site hours (HPE) : **6,00**

Description

The potential of the lignocellulosic biomass can be exploited for the production of materials, as well as second-generation biofuels and bio-based molecules. Indeed, it is an additional resource to first-generation biomass and has a wide variety of molecules of interest.
However, its industrial exploitation is hindered by its structure which is recalcitrant for standard fractionation processes.
The implementation of pre-treatments is therefore required for the industrial valorization of lignocellulosic biomass.

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

After presenting the properties of lignocellulosic biomass, several pre-treatment processes will be detailed:

- Drying,
- Torrefaction,
- Grinding,
- Enzymatic hydrolysis,
- Chemical hydrolysis (alkaline, acid, solvolysis).

Class components (lecture, labs, etc.)

The course module is organized in lectures (6 hrs).

Grading

The course is evaluated through a multiple choice test at the end of the lecture.

Course support, bibliography

- Pang S.; Bhattacharya S.; Yan J. *Drying of biomass, biosolids, and coal for efficient energy supply and environmental benefits*, CRC Press, 2019, 200 p.
- Bergman P.CA.; Boersma A.R.; Zwart R.W.R.; Kiel J.H.A. *Torrefaction for biomass co-firing in existing coal-fired power stations*, Biocaol, 2005, 72 p.
- Mujumdar A.S. *Handbook of industrial drying*, 3rd Edition, CRC Press, 2006, 1312 p.
- Chen H.; Wang, L. *Technologies for biochemical conversion of biomass,* Academic Press, 2016, 284 p.

- Perré P. *Le séchage du bois*, in Le bois, matériau d'ingénierie, ARBOLOR, 1994. pp. 201-287
- Stickel J.J.; Elander R.T.; Mcmillan J.D.; Brunecky R. Enzymatic hydrolysis of lignocellulosic biomass, in *Bioprocessing of renewable resources to commodity bioproducts*, John Wiley & Sons, 2014, pp. 77-103

Resources

Teaching staff: Julien COLIN and Pedro AUGUSTO

Learning outcomes covered on the course

At the end of this course, students will be able to:

- To provide an overview of pre-treatment processes for lignocellulosic biomass,
- Understand the mechanisms implemented for each pre-treatment.

Description of the skills acquired at the end of the course

C2: Acquire and develop broad skills in a scientific or academic field and applied professional areas

3VS2060 – Bioprocess Engineering - Bioprocess

Instructors : **Filipa Lopes**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **68**
On-site hours (HPE) : **48,00**

Description

Bioprocess are aimed at producing biomass and biocompounds by using different types of microorganisms (natural or genetically modified). Applications are very broad and include many industrial applications in mature sectors, with significant employment potential, such as food, chemistry (biosolvents, surfactants, enzymes), pharmaceutics and cosmetics (antibiotics, recombinant proteins, biopolymers, etc) industries, as well as emerging sectors with high potential (renewable chemistry, biofuel, biomaterials, etc).

The aim of this course is to train engineers (1) to take into account the biological constraints in the process development and design in order to master the industrial production of biomass and related biocompounds (2) to implement and scale-up bioprocesses and to scale-up bioreactors taking into account quality and economic performance constraints; (3) to work at the interface of several disciplinary fields (microbiology, process engineering, control).

Quarter number

SG10

Prerequisites (in terms of CS courses)

Transfer Science (1A), Process Engineering for Sustainable Development (2A, recommended).

Syllabus

- Microbial kinetics
- Implementation of a bioprocess
- Scale-up of bioreactors
- Bioprocess simulations
- Industrial bioproductions : 1) Solid-state fermentation, 2) Biofuel, 3) Organic acids, 4) Biopolymers, 5) Microalgae.

Class components (lecture, labs, etc.)

Bioprocess principles will be illustrated with realistic examples and addressed in the form of lectures, tutorials and simulation sequences on dedicated softwares. The application of the studied principles to different industrial sectors will be illustrated in the form of conferences.

Grading

Written examination.

Course support, bibliography

Books:

- El Mansi E.M.T., Nielsen J., Mousdale D., Allman T., Carlson R. (2019). Fermentation microbiology and Biotechnology (4th Ed.). CRC Press (Boca Raton, FL).
- Mc Neil B., Harvey L.M. (1990). Fermentation: A practical approach. IRL Press (Oxford, England).
- Rehm H.J. & Reed G. (1995-2001). Biotechnology, a multi-volume comprehensive treatise. Vol 1: Biological fundamentals; Vol 3: Bioprocessing; Vol 4: Measuring, modelling and control; Vol 6: Products of primary metabolism; Vol 7: Products of secondary metabolism. VCH (Weinheim, Allemagne).

Presentations of the various speakers.

Resources

Teaching team : Catherine Béal (Pr, AgroParisTech), Sophie Landaud (Pr, AgroParisTech), Claire Saulou-Bérion (MCF, AgroParisTech), Julien Colin (MCF, Centrale Supélec), Behnam Taidi (Pr, CentraleSupélec), Filipa Lopes (Pr Centrale Supélec), speakers from industry.

Learning outcomes covered on the course

By the end of this course, the student will be able to :

- Identify the different steps of a bioprocess,
- Estimate microbial kinetics (growth and biocompounds production),
- Propose the most appropriate reactor's operating mode (batch, continuous, fed-batch) for a given application,
- Write the mass balance for a given bioprocess,
- Scale-up a bioreactor taking into account biological and technological constraints.

Description of the skills acquired at the end of the course

C1, C2

3VS2070 – Bioprocess Engineering - Downstream processing

Instructors : **Filipa Lopes, Julien Lemaire**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Downstream Processing, applied to industrial biotechnology, is defined as "all unitary operations aimed at extracting and purifying biomolecules resulting from the fractionation or bioconversion of renewable materials".
It is an essential step in plant biorefineries, which aim to substitute fossil resources and develop new, more sober and ecological production processes. Indeed, it is generally the most expensive and the most impacting on the environment because of the number of operations required to obtain the marketable product(s).
The general objective is to train executives capable of defining innovative, competitive and more environmentally friendly separation strategies by cleverly choosing and combining modern or more conventional technologies.
After the presentation of a rather broad panorama of usual techniques, a reasoned choice guide will be proposed as well as courses to learn how to optimize and pre-scale certain processes that are essential in biorefineries such as membrane filtration, electrodialysis, ion exchange, adsorption, gas-liquid absorption, liquid-liquid extraction, distillation or preparative chromatography.
The concepts covered in this course are essential and complementary to the other courses of the "Environment and Sustainable Production" mention. The interest of this course will be particularly illustrated during the Biorefinery Immersion Week.

Quarter number

SG10

Prerequisites (in terms of CS courses)

Transfer Science (elective 1A), Process Engineering (elective 2A)

Syllabus

Detailed Course Outline : "Overview of separative techniques in biotechnology" (3h), "Comparison and reasoned choice guide, eco-design of processes" (3h), "Case study, group project presentation and discussion" (3h), "Focus on conventional processes" (3h), "Focus on membrane processes" (3h), "Focus on chromatographic processes" (3h)

Class components (lecture, labs, etc.)

This teaching is composed of lectures in which general principles are presented, illustrated with examples and industrial applications. Tutorials are associated with some courses in order to learn how to carry out fundamental numeric applications.

At the same time, the students, working in teams (4 to 5 students depending on the total number of students), will work on a bibliographical study project around a case study in order to apply the lessons of this course and take a step back. The aim will be to propose one or more separation strategies in the context of a biosourced molecule production (derived from plant co-products or obtained by biotechnology). The work will be presented to the whole class (15 min of presentation followed by 5 to 10 min of discussion) during the last session.

Grading

Session 1 : MCQ-type written exam (60%), Oral presentation of the project (40% - collective and individual grade)

Session 2 : MCQ-type written exam (75%), Oral presentation of the project (25% - note carried over from session 1)

Course support, bibliography

Pdf support of the different courses
Engineering techniques :

1- C. CHIRAT, Lignocellulosic biorefineries: Extraction and valorisation of hemicelluloses, RE279, July 2019.
2- F. BROUST et al, Second-generation biofuels and biorefineries, RE110, February 2013.
3- L.-M. SUN et al, Adsorption: Processes and applications, J2731, December 2015.
4- B. VEYNACHTER and P. POTTIER, Centrifugation et décantation, F2730, March 2007.
5- F. PUEL et al, Crystallization: Theoretical aspects, J2710, June 2005.
6- F. DE DARDEL, Ion exchange : Applications, J2785, June 2016.
7- F. CHEMAT et al, The six principles of plant eco-extraction, J4922, November 2018.
8- H. ROUX DE BALMANN and E. CASADEMONT, Electrodialysis, J2840, September 2006.
9- M. DECLOUX and B. RÉMOND, Evaporation, Techniques de l'Ingénieur, F3003, June 2009.
10- G. GÉSAN-GUIZIOU, Membrane Filtration: Applications in Food Processing, J2795, December 2007.
11- P. AIMAR and G. DAUFIN, Membrane separations in the food industry, F3250, December 2004.

Resources

Teaching staff: Julien Lemaire (Process Dept.), Lectures with TD + Project-based learning (case study to be dealt with in groups of 4 or 5 students)

Learning outcomes covered on the course

To identify the main separation techniques used in biotechnology, Identify their advantages and disadvantages, Understanding the problems of coupling separation processes, Knowing how to choose and combine the most suitable techniques, Know how to take into account technical, economic and environmental constraints, Know how to make material balances to pre-scale certain processes

Description of the skills acquired at the end of the course

- C1
- C2
- C3
- C7
- C8

3VS2110 – Environmental Engineering - Water treatment

Instructors : **Filipa Lopes, Cristian-Felipe Puentes Mancipe**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **75**
On-site hours (HPE) : **45,00**

Description

Water is a natural resource essential for the development of life. Its importance in the economy and its unequal distribution on Earth make its management and preservation a major geopolitical issue.
Human and industrial activities have disrupted water regimes and their natural functions. They are also at the origin of the pollution of water resources, which can be biological or chemical in nature. Various strategies have been developed to control this pollution and thus reduce its impact on the environment.

This course aims to provide essential knowledge about water resources as well as water purification and wastewater treatment, two fairly mature decontamination strategies involved in the domestic water cycle before it is returned to nature. It also aims at mastering all the operations that allow the predictive treatment of the behavior of complex liquid media, involved in wet processes present in a large number of industrial sectors.
These notions will enable future engineers to better grasp the complexity and the stakes of a controlled and efficient management of water supply in 21st century societies.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Recommended: Process engineering: application to the environment and biomanufacturing (ST5-specific course 2SC5210 or SG8-elective 2A-2EL2040)

Syllabus

– *Introductory conference:* Geopolitics of water

– *Introductory conference:* Water cycle, natural resource assessment
– Physical chemistry of water: complexation, selective solubilization and insolubilization in aqueous solution
– Natural resource modeling
– Water purification

– Sanitary component of drinking water supply
– Ecologie microbienne des procédés de traitement des effluents
– Urban wastewater treatment

– Industrial wastewater treatment
– Water treatment project management
– Visit of a site for water capture and purification and/or domestic wastewater treatment

Class components (lecture, labs, etc.)

This teaching is mainly composed of lectures with a few tutorial sessions to go into more detail on specific aspects (solubilization/insolubilization and complexation in aqueous solution, water flow in nature and urban wastewater treatment processes).
In order to visualize the level of complexity and maturity of water treatment processes, students will have the opportunity to visit a site for water capture and purification and/or domestic wastewater treatment in the Paris region.

Grading

Graded tutorial (30%); analysis and presentation of a case study (70%)

Course support, bibliography

Course presentations

Books:
– BREZONIK P. L. and ARNOLD W. A., Water Chemistry: An Introduction to the Chemistry of Natural and Engineered Aquatic Systems, Oxford University Press, 2011

Techniques de l’ingénieur (in french):
– BOEGLIN J.C., Traitement biologique des eaux résiduaires, J3942 V1, Décembre 1998.
– BOEGLIN J.C., Traitements et dispositions finales de boues résiduaires, J3944 V1, Septembre 2000.
– GAÏD A., Traitement des eaux résiduaires, C5220 V1, Février 2008.
– SPERANDIO M., HERAN M., GUILLOT S., Modélisation biologique des procédés biologiques de traitement des eaux, W6500 V1, Août 2007

Resources

– Teaching team: the speakers are specialists in the field of water treatment from industry and academia.
– Software tools: Matlab for resource modeling tutorial, Software West for wastewater treatment tutorial.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:
– Predict the behavior of a given medium for a set objective or to design new processes related to the decontamination of aqueous effluents or waste recycling.
– Model the flow of a water resource in nature.
– Identify and describe the stages of water purification treatment.
– Understand and simulate certain urban wastewater treatment processes in wastewater treatment plants.
– Acquire basic notions on industrial water treatment technologies.

Description of the skills acquired at the end of the course

- C1.1, milestone 3 --> assessment through a case study (written report and oral defense)
- C2.3, milestone 3 --> assessment through a case study (written report and oral defense)
- C7.1, milestone 3 --> assessment through a case study (oral presentation)

3VS2120 – Environmental engineering - Air and waste gas treatment.

Instructors : **Cristian-Felipe Puentes Mancipe, Filipa Lopes**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **15**
On-site hours (HPE) : **9,00**

Description

Gaseous emissions generated by human activities are the source of various pollutants that have an impact on human health and the environment. The control and reduction of these emissions are the subject of international agreements on a global scale.
The objective of this course is to make students aware of the environmental problems related to gases. Two main topics are covered: on the one hand, pollution and air quality, and on the other hand, industrial gas effluent treatment processes.
This knowledge will be essential for future engineers involved, for example, in air pollution control or in the treatment of gaseous emissions in sectors such as the environment and biotechnology. They will be able to play an active role in optimizing mature processes and developing emerging technologies.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Recommended: Process engineering: application to the environment and sustainable production (ST5-specific course 2SC5210 or SG8-elective 2A-2EL2040)

Syllabus

– Pollution and air quality issues: monitoring tools.
– Analysis of gaseous effluent treatment processes.
– Focus on gas scrubbing by absorption (principle and sizing).

Class components (lecture, labs, etc.)

This course consists of lectures and numerical simulation tutorials to illustrate some gas treatment processes.

Grading

Case study of numerical simulation with commercial software (100%)

Course support, bibliography

Course presentations

Techniques de l'ingénieur (in french):
– LE CLOIREC P., Procédés de dépollution des émissions gazeuses industrielles, J3921 V2, Février 2016
– LE CLOIREC P., Introduction aux traitements de l'air, G1700 V3, Février 2016

Resources

– Teaching team: the speakers are specialists in air quality monitoring and gaseous effluent treatment.

Learning outcomes covered on the course

At the end of this teaching, the student will be able to:
– Understand the concept of air quality and the associated environmental issues.
– Identify and describe the treatment of industrial gaseous effluents through physical, chemical and biological processes.
- Simulate gas treatment processes (e.g. physical and chemical absorption) for different applications (e.g. CO_2 capture, natural gas drying) using commercial software.

Description of the skills acquired at the end of the course

- C1.1, milestone 2 --> assessment through case study of numerical simulation
- C2.3, milestone 2 --> assessment through a case study of numerical simulation

3VS2130 – Environmental Engineering - waste treatment

Instructors : **Filipa Lopes, Cristian-Felipe Puentes Mancipe**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

We constantly produce a multitude of waste products, residues that are discarded after primary use. They are often bulky and in some cases dangerous. Good management of these residues is essential to protect human health and control environmental impacts. As a problematic consequence of urbanization and industrialization, wastes also represent an opportunity for transition to a circular economy when they are used as a resource through recovery, recycling or reuse.
The aim of this course is to provide a general overview of solid wastes, the regulations associated with its management and treatment processes. A focus will be made on two classical forms of waste disposal, with important tonnages (incineration, landfill) then on a disposal approach with evolving tonnages in connection with industrial biotechnology (composting, anaerobic digestion). These elements will enable future engineers to identify development and innovation opportunities in this field, both in the public sector and for private operators.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Recommended: Process engineering: application to the environment and sustainable production (ST5-specific course 2SC5210 or SG8-elective 2A-2EL2040)

Syllabus

– Introduction on waste: definition, nature, volume, European legislation.
– Waste management methods (collection and treatment processes): hierarchy, link with the circular economy and with the social dimension (reuse, prevention).
– Analysis of 2 classic disposal methods (large tonnage): incineration and burial.
– Analysis of 2 biological disposal methods (emerging technologies with a changing tonnage of waste treated): composting and methanisation.
– Visit of a waste management center.

Class components (lecture, labs, etc.)

This course consists mainly of lectures. It is complemented by a technical visit in the Paris region, which will give a better understanding of the treatment tonnages as well as the organisation and complexity of the processes and installations.
Evaluation

Grading

MCQ written exam (25%); analysis and presentation of a case study (75%)

Course support, bibliography

Course presentations

Techniques de l’ingénieur (in french):
– NAVARRO A., Approche systémique des déchets, G2000 V2, Mars 2016
– BAYARD R., GOURDON R., Traitement biologique des déchets, G2060 v2, Janvier 2010

Resources

– Teaching staff : The speakers are academic or industrial experts in solid waste management

Learning outcomes covered on the course

At the end of this course, the student will be able to:
– Describe the concept of waste and the main principles of European regulations for its classification and management.
– Identify waste treatment methods and their hierarchy.
– Understand the principles of waste treatment by incineration and landfills.
– Acquire basic notions on biological treatments of composting and anaerobic digestion.

Description of the skills acquired at the end of the course

- C1.1, milestone 3 --> assessment through a case study (written report and oral defense)
- C2.3, milestone 3 --> assessment through a case study (written report and oral defense)
- C7.1, milestone 3 --> assessment through a case study (oral presentation)

3VS2140 – Circular Economy of Industrial Processes - Eco-design/Life Cycle Analysis

Instructors : **Yann LEROY, Filipa Lopes**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

Life Cycle Assessment (LCA) is a well-known approach to evaluate the environmental impacts of a system (product, process, or service). LCA is defined as the characterization and the quantification of inputs, outputs (material and energy streams), and potential environmental impacts over its entire life cycle. LCA is a standardized approach characterized by:
- quantitative assessment of materials and energy streams and environmental impacts
- multicriteria approach integrating several environmental impacts and damages (global warming potential, abiotic depletion, eutrophication, ozone depletion…)
- life cycle thinking considering the entire life cycle of a system from raw material extraction to disposal and end-of-life strategy.
LCA is widely used for several applications such as Ecodesign, environmental communication (Label), technological and investment decision, policymaking.

Quarter number

SG11

Prerequisites (in terms of CS courses)

None

Class components (lecture, labs, etc.)

Lectures and workshops

Grading

The evaluation relates to both an oral presentation and a technical report of the realized LCA.

Resources

The course alternates lectures and workshops. These workshops consist in performing an LCA in small groups of students.

Learning outcomes covered on the course

- Describe and model the life cycle of a system
- Frame and perform an LCA with respect to ISO 14040 standard
- Model and simulate the environmental performance of a system with an LCA software and its databases
- Understand LCA results

Description of the skills acquired at the end of the course

C1 Analyser, concevoir et réaliser des systèmes complexes à composantes scientifiques, technologiques, humaines et économiques
C1.1 Analyser : étudier un système dans sa globalité, la situation dans son ensemble. Identifier, formuler et analyser un système dans le cadre d’une approche transdisciplinaire avec ses dimensions scientifiques, économiques, humaines, etc.
C1.2 Modéliser : utiliser et développer les modèles adaptés, choisir la bonne échelle de modélisation et les hypothèses simplificatrices pertinentes
C1.3 Résoudre : résoudre un problème avec une pratique de l'approximation, de la simulation et de l'expérimentation
C2 Développer une compétence approfondie dans un domaine d’ingénieur et dans une famille de métiers
C2.1 Approfondir un domaine des sciences de l'ingénieur ou une discipline scientifique
C7 Savoir convaincre
C7.1 Sur le fond : Structurer ses idées et son argumentation, être synthétique (hypothèses, objectifs, résultats attendus, démarche et valeur créée)
C9 Penser et agir en ingénieur éthique, responsable et intègre en prenant en compte les dimensions environnementales, sociales et sociétales
C9.2 Analyser et anticiper les conséquences possibles des organisations et modèles économiques des structures auxquelles on contribue

3VS2160 – Biorefinery Immersion Seminar

Instructors : **Filipa Lopes, Julien Lemaire**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

This biorefinery immersion week aims to make students aware of the realities on the ground by integrating into their thinking the societal, environmental, economic and technical constraints and issues related to the problem of scale change.
It is an opportunity to apply a large part of the knowledge acquired during the 1st semester, in particular the "Environment, Sustainable Production" Mention, and more particularly in industrial biotechnologies.
Students will have the opportunity to visit an academic research centre (CEBB), an R&D company (ARD) and industrial facilities, in the renowned Bazancourt-Pomacle biorefinery, which is a model of industrial ecology and circular economy. This site, comprising a sugar refinery, a sugar and starch factory and one of the largest distilleries in Europe, has been able to develop exceptional industrial and territorial synergies. It is a showcase for the promotion of the bio-economy at the global level.
This week includes 3 days of experimental activities to illustrate the skills to be implemented to develop new biomass transformation processes: multi-scale experimentation and modelling, multi-criteria analysis and optimisation, taking into account complexity and uncertainty.
The general objective of this course is to train executives capable of solving complex problems in the field of industrial biotechnology, sustainable production, the environment, and more generally the bioeconomy. In particular, this week aims to enable students to take a step back and understand the complexity and all the constraints to be considered in the management of an industrial project.

Quarter number

SG11

Prerequisites (in terms of CS courses)

Course of the "Environment, Sustainable Production" mention in SG10 and more generally of the SVE dominant in SM9.

Syllabus

Monday
9h30-11h: Welcome, presentation of the programme, the evaluation method and reminder of safety instructions.
11h-12h30: Presentation of the biorefinery and visit of the CEBB " European Centre for Biotechnology and Bioeconomy ".
13h30-16h30: Visit of the sugar factory Cristal Union
Tuesday
9h-16h30: Practical work n°1: TP n°1 with the pilot group
Wednesday
9h-16h30: Practical work n°2
Thursday
9h-16h30: Practical work n°3
Friday
9h-12h: Oral presentations by the pilot groups
13h30-15h: Visit of ARD "Agro-Resources Research & Development" and their demonstration platform "Biodémo".
15h-16h30: Visit of the bioethanol factory Cristanol

Class components (lecture, labs, etc.)

Experimental activities
Depending on the number of students, 3 to 5 groups of 3 to 4 students will be composed.
Here is an example of suggested subjects, which may change from one year to the next:
- "Study of ethanol production by Saccharomyces cerevisiae in a 2 L bioreactor"
- "Study of an innovative process for the purification of acid hydrolysate pentoses from hemicelluloses by a combination of ultrafiltration and conventional electrodialysis"
- "Study of the conventional process of purification/demineralization of acid hydrolysate of hemicellulose by chemical precipitation and ion exchange"
- " Study of a process for upgrading sauerkraut juice by simulated moving bed chromatography "
- "Study of the recovery of biosourced organic industrial waste by enzymatic hydrolysis, after pre-treatment by acid cooking"
- "Study of a biogas purification process by gas-liquid absorption using membrane contactors"

Each of the groups will have to choose a "pilot" topic that they will study in depth. They will compile the data obtained by the other two groups that did this work and use the results as a whole. On the first day, each group will start with the chosen "pilot" TP. On the following 2 days, they will do 2 other TPs according to the predefined rotation.

Grading

The quality of the experimental work (care taken, autonomy, dynamism) will be evaluated by the supervisors: individual grade for each works (the average of the 3 grades counts for 25% of the final grade).
A short oral presentation by the "pilot" groups will take place on Friday morning, consisting of 10 to 15 minutes of presentation followed by 5 to 10 minutes of questions (the average of individual and group grade counts for 25% of the final grade).
Finally, a 15 to 20 page report on the "pilot" TP will be due one week later. Precise instructions will be given by the supervisor (the corresponding grade counts for 50% of the final grade).

Resources

Teaching team
- Julien Lemaire: Associate professor
- Pedro Augusto: Professor
- Rafik Balti: Professor
- Fanny Duval: Assistant engineer in Separation Techniques
- Emilie Michiels: Assistant engineer in biotechnologies
- Fiona Mateus: Technician in biotechnologies

CEBB's technical means for carrying out experimental activities.

Learning outcomes covered on the course

1) Be aware of the issues of the bio-economy
2) Identify strategies for biomass valorisation, energy optimisation, industrial ecology and circular economy
3) Knowing how to solve a complex problem with various technical, economic and environmental constraints, and several parameters to be optimized
4) Understanding the issues related to the change of scale
5) Knowing how to couple experimental and numerical approaches for decision support (optimization, dimensioning, forecasting, ...)
6) Identify the main processes used in plant biorefinery and industrial biotechnologies

Description of the skills acquired at the end of the course

- C1
- C2
- C3
- C7
- C8
- C9

3VS2500 – VSE ESP Project

Instructors : **Filipa Lopes**
Department : **MENTION ENVIRONNEMENT ET PRODUCTION DURABLES (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

In pairs, the students will carry out a mention project (120 hours per hour), with the aim of producing a deliverable (software, prototype, scientific study) for an academic or industrial client in the fields of processes/bioprocesses and the environment. These projects can also be proposed by students who carry out an entrepreneurial project.

Quarter number

SD9, SG10, SG11

Prerequisites (in terms of CS courses)

Scientific prerequisites according to the subject

Class components (lecture, labs, etc.)

The work will be carried out in priority at the School, but a partial welcome at the partner's home is possible. Students will be supervised by a tutor from the partner and followed by an academic tutor from the School. The modalities of accompaniment are variable (face to face meetings, telephone appointments, exchange of emails). The deliverables of these projects can be, for example, a process dimensioning calculation, a model, a software, a data analysis, a technico-economic study.

Grading

Mid-term defense (early February) and final defense (mid-April) with delivery of a report and deliverables to the client.

Resources

Computer and experimental facilities available at CentraleSupélec

Learning outcomes covered on the course

The project of mention constitutes an experience of scientific or technico-economic project management in the fields of processes/bioprocesses and the environment. The scientific and technical skills mobilized in an innovation objective are complemented by a knowledge of how to behave towards the partner as well as by methods of project management/team management.

Description of the skills acquired at the end of the course

C1, C2, C3, C4, C7, C8, C9

3VS3010 – Medical Imaging Technology

Instructors : **Emmanuel Odic**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **40**
On-site hours (HPE) : **24,00**

Description

Medical imaging is one of the pillars of medical care and medical research. Magnetic resonance imaging will be presented (advanced technique). At the end of this module, students will be able to (i) understand the physical principles used in an advanced imaging technique, (ii) master the tomographic reconstruction algorithms, (iii) grasp the challenges of neuroimaging, (iv) understand the possibilities offered by functional imaging. The speakers are from General Electric Healthcare and CEA Neurospin.

Quarter number

SG10

Prerequisites (in terms of CS courses)

No prerequisites

Grading

Written test

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C2. Develop in-depth competence in a scientific or sectoral field and a family of professions
C9. Act as a responsible professional. Think and act ethically.

3VS3020 – Image processing

Instructors : **Emmanuel Odic, Elisabeth LAHALLE**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

The points of view of image analysis are as follows: extracting relevant information from images regarding the application, processing and interpreting them. The information modeling, the preprocessing to get an image of good quality, the detection and the estimation of region attribute or point of interest are detailed through efficient concepts and methods. The purpose of this course is to present the images analysis methods which are chosen for their relevance as well as for the quality of their results.

Quarter number

SG10

Prerequisites (in terms of CS courses)

- Signal processing: convolution, Fourier transform and related properties
- Probability/ statistics
- PDE
- Optimization

Syllabus

Basic analysis:
-Introduction
Definitions, Motivation.
- Statistical and spectral properties
Histogram, region attribute, cooccurence matrix,
spectral representation,
Filtering, Gaussian and DOG, pyramids
- Sampling-interpolation
-Preprocessing
Contrast enhancement: pseudo-colors, histogram modifications and equalization, linear filtering.
Noise reduction : linear filtering, rank filtering, homomorphic filtering, filtering using partial differential equation.
Registration
-Edge detection
Local approaches: Sobel, DOG,LOG, optimal filter: Canny,
Global approach : snakes (principle)
- Boundary and specific elements detection
Shape finding: Hough transform,
Singular point finding.
Fourier descriptor
Mathematical morphology:
- Basic concepts-elementary operations
- Compound operations
- Morphological filtering - particle size analysis
- Discrete topology
- Segmentation by mathematical morphology

Class components (lecture, labs, etc.)

The course is organized in two parts to present :

- **Basic image processing :** 3 lectures, 3 TD
- **Mathematical morphology :** 8 lectures

The main concepts will be illustrated and some image processing algorithms will be implemented using a simulation software such as Matlab or python

Grading

Project report

Course support, bibliography

M. Petrou and P. Bosdogianni, "Image processing. The fundamentals", John Wiley 1999
L. Najamand H. Talbot (Editors), Mathematical morphology, Wiley-ISTE, 2010

Resources

Room with computers and Matlab software for practical sessions (TD)

Learning outcomes covered on the course

- Ability to analyze a numerical image
- Ability to implement elementary numerical images algorithms

Description of the skills acquired at the end of the course

- Master the basic processing of digital images:
  histogram calculation and transformation, linear or non-linear filtering, smoothing and edge detection.
- Know how to analyze the content of a digital image.
- Assimilate more advanced concepts:
  denoising using PDE, segmentation based on geometric models of the image (edge), non-linear filtering and its formalization, applications of graph theory, pattern recognition

3VS3030 – Deep learning and NLP for diagnostic

Instructors : **Emmanuel Odic, Arthur Tenenhaus**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **55**
On-site hours (HPE) : **33,00**

Description

This course covers practical techniques of optimization deep neural networks. Students will be able study and implement advanced learning models on complex (medical) data, through the following techniques and tools:

- Libraries Numpy, TensorFlow (Keras)
- Optimization techniques, transfer learning and regularization
- Understanding of classical model architectures and overview of the state of the art

In particular, students will implement methods for the following applications:

- Image analysis through deep convolutional networks;
- language analysis by unsupervised learning of representations of words and recurrent and transformer networks;
- other applications such as recommendation engines, generative models ...

Quarter number

SG10

Prerequisites (in terms of CS courses)

This course is for students who have already studied Machine Learning and numerical optimization. It consists of many practical sessions (laptop required).
The technical prerequisites are Python language (especially in jupyter, concepts and numpy scikit-learn).

Syllabus

- Intro to Deep Learning
- Neural Networks and Backpropagation
- Embeddings and Recommender Systems
- Convolutional Neural Networks for Image Classification
- Deep Learning for Object Detection and Image Segmentation
- Recurrent Neural Networks and NLP
- Sequence to sequence, attention and memory
- Unsupervised Deep Learning and Generative models

Class components (lecture, labs, etc.)

Mix between lectures and practical sessions

Grading

Continuous assessment at the beginning of some practical work session, and final evaluation (coding session).

Course support, bibliography

LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. *nature*, *521*(7553), 436-444

Learning outcomes covered on the course

At the end of this course, students will have a theoretical and practical knowledge of the main methods of Deep Learning. Students will know, for a given problem, how to identify the best class of models class and how to implement them in practice.

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C2. Develop in-depth competence in a scientific or sectoral field and a family of professions
C9. Act as a responsible professional. Think and act ethically.

3VS3040 – Dynamical Systems and Computational Neuroscience

Instructors : **Antoine Chaillet**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **42**
On-site hours (HPE) : **25,00**

Description

This course constitutes an introduction to tools for the analysis of dynamical processes involved in brain functioning. Despite their huge complexity, brain functions are indeed based on elementary dynamics, some of which can be apprehended by a mathematical approach. Mastering these techniques is fundamental to progress in our understanding of brain functioning, to optimize instrumentation for brain activity measurements (brain imaging, electrophysiological recordings...), to improve brain- machine interfaces, to build up neuro-inspired computational units, and to understand the mechanisms involved in some brain diseases and thus improve their treatment.

Quarter number

SG10

Prerequisites (in terms of CS courses)

- ST2 : Modeling
- ST4 : Signal processing
- ST5 : Control Theory

Syllabus

Chapter 1 : Mathematical models of neurons (Sabir Jacquir, CM 3h)
This chapter presents the most common neuron models. It introduces conductance-based models through the famous Hodgkin-Huxley model and underlines its analogy with electronics. It then introduces simplified models such as Integrate & Fire or FitzHug-Nagumo. An introduction to the numerical simulation of these models is also presented. It also addresses synaptic modeling and the exploration of synaptic plasticity. It covers the Hebbian theory of plasticity mechanisms and the STDP which takes into account the timing at which action potentials are received by the neuron, and presents the corresponding mathematical models. It also links these mechanisms to leaning principles used in Artificial Intelligence.

Chapter 2 : Analysis of neuron models (Antoine Chaillet, CM 4h30)
This second chapter presents mathematical tools used in the analysis of bi-dimensional neuron models. It presents different kinds of bifurcations that can be involved in the qualitative change of the neuron behavior and provides a link between these bifurcations and the computational properties of the neuron, such as: existence or not of an activation threshold (bistability), repeated or isolated action potentials, resonant or integrator properties of the neuron, etc..

Chapitre 3 : Biophysical model of a neuron (Alain Destexhe, CM 1h)
This chapter presents a realistic neuron model that takes into account the dynamics of its dendrites.

Chapitre 4 : « Mean field » models of neuronal populations (Alain Destexhe, CM 2h)

This fourth chapter addresses the dynamics of a whole population of neurons or an entire brain structure using "mean field" models. In particular, it shows how to derive such models based on the action potentials of the neurons involved.

TP1 : Analysis and simulation of a « mean field » model (Sabir Jacquir, TP 3h)
This first lab session constitutes an introduction to the simulation program Bryan (developed on Python) for the simulation of "mean field" models.

Chapter 5 : « Neural field » models of neuronal populations (Antoine Chaillet, CM 3h)
This fifth chapter addresses the dynamics of a neuronal population based on models inspired by the works of Wilson and Cowan, which summarize the activity of the population through the temporal evolution of its firing rate. It shows how to mathematically predict the behavior of such models through stability and bifurcation analysis. It also proposes tools to identify such models based on electrophysiological measurements.

TP2 : Binocular rivalry (Antoine Chaillet, TP 3h)
This second lab session employs a neuronal population model to explain the phenomenon of binocular rivalry that occurs when a different image is presented to each eye. It comprises its Matlab-Simulink implementation and the validation of mathematical predictions.

Chapter 6 : Introduction to neuromorphic computing (Andrew Davison, CM 3h30)
This last chapter presents some computers developed specifically for the simulation neural networks and brain-inspired computing architectures.

Class components (lecture, labs, etc.)

This course is made of lectures and lab sessions. Although no exercise classes are explicitly scheduled, several examples and exercises will be presented during the lectures, for which an active participation of the student is requested.

Grading

Evaluation will be made based on a written exam without documents (2h) at the end of the course and on the written reports of the two lab sessions. The following weights are envisioned: 60% for the written exam and 20% for each lab session report.
Any unjustified absence at the TP will lead to a zero as lab session grade.

Course support, bibliography

- Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting, Eugene M. Izhikevich, The MIT Press, 2007
- Nonlinear dynamics and Chaos, by Steven Strogatz, Westview Press, 2001
- Mathematical Foundations of Neuroscience, by G. Bard Ermentrout & D. Terman, Springer, 2010
- Theoretical neuroscience, by P. Dayan & L.F. Abbott, The MIT Press, 2005

Resources

The teaching team is made of researchers and professors in computational neuroscience and a professor of the Automatic Control department.
Lab sessions will take place on computers equiped with Python and Matlab-Simulink.

Learning outcomes covered on the course

At the end of this course, students will have acquired basic neuroscience knowledge to allow interaction with professionals of the field (neurosurgeons, computational neuroscientists, experimenters). They will know of mathematical tools to model activity of a single neuron or a whole neuronal population, and to predict their dynamical properties both analytically and through simulations. They will also have been made aware of opportunities offered by neuroscience in terms of research, medical and industrial development, and entrepreneurship.

Description of the skills acquired at the end of the course

By the end of this course, students will be able to:
 - Understand neuroscience fundamentals, for possible interaction with professionals of the field (neurosurgeons, computational neuroscientists, experimenters)
 - Model the activity of a neuron or a whole neuronal population
 - Predict their behavior both analytically and numerically.

This course will thus be an opportunity to deepen skills:
 - C1.2: "Use and develop adequate models, choose the right modeling scale and the right simplifying assumptions to treat a problem": Jalon 3
 - C1.3: "Solve a problem by employing approximation, simulation and experiments": Jalon 2A
 - C1.5: "Use a wide scientific and technical background in the context of a transdisciplinary approach"
 - C2.2: "Transpose to other fields, generalize knowledge"
 - C2.3: "Quickly identify and acquire new knowledge and skills in relevant domains (technical, economical or other)".

3VS3050 – Bioinformatics

Instructors : **Pascale Le Gall, Emmanuel Odic**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

The objective is to acquire the foundations of bioinformatics, algorithmic analysis of genetic data (sequence alignment, phylogenetic reconstruction, etc.), to know the main algorithms.

Quarter number

SG11

Prerequisites (in terms of CS courses)

- Programming in Python
- Basic knowledge of algorithms (design, analysis, complexity)

Syllabus

1. Introduction to bioinformatics (genomic sequences, algorithms)
2. Exact algorithms for pattern search
3. Alignment of biological sequences: global alignment, local alignment, multiple alignments
4. Prediction of secondary RNA structures
5. Text analysis with suffix trees
6. Introduction to phylogeny.

Class components (lecture, labs, etc.)

Alternating courses and tds sessions

Grading

Written examination (1h30) with documents

Course support, bibliography

Copies of the slides, exercise topics and their answers

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C2. Develop in-depth competence in a scientific or sectoral field and a family of professions
C9. Act as a responsible professional. Think and act ethically.

3VS3060 – Physical techniques of medical treatment

Instructors : **Emmanuel Odic**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **25**
On-site hours (HPE) : **15,00**

Description

This teaching unit focuses on two types of physical treatment of cancer pathologies. The first deals with radiotherapy in general and more specifically with proton therapy, which is now used to treat patients, in particular at the Institut Curie Proton Therapy Center located on the Orsay Paris-Saclay campus.
The second, more upstream, concerns technologies using cold plasmas. This type of technology is currently being tested in research laboratories in partnership with hospitals. It is therefore a prospective axis.

Quarter number

SG11

Prerequisites (in terms of CS courses)

No prerequisites

Syllabus

Proton therapy (9 HPE)
Radiotherapy is one of the major modalities used in the treatment of cancer. Conventional radiotherapy treatment devices, often called "Linacs", are based on electron gas pedals. This industrial park represents thousands of devices installed in most hospitals around the world. Proton therapy, whose principle is to use protons, was only experimented in the 1960s and 1970s, with the advantage of ballistics far superior to conventional radiotherapy, but at a cost and complexity that initially made it unthinkable. Its emergence and development took several years. Today it is used with patients who are still very specific.
Cold plasmas (6 HPE)
Cold plasmas are partially ionized gases in which the temperature of the "heavy" ones (neutrals and ions) remains close to room temperature while the electrons reach high energies (temperatures) (10-16 eV or ~ 105 K). This type of plasma can be produced by electric discharge in a gas or bombardment by an electron beam. By direct impact of energetic electrons on the atoms or molecules of the gas, highly reactive species are produced (ions, excited species, atoms and radicals in the case of dissociation of molecules), some of which emit radiation (UV-visible) by spontaneous radiative de-excitation. These species and their recombination products are likely to interact with solid or liquid surfaces. Thus, cold plasmas have been widely used for surface treatment in the fields of microelectronics, polymers or drinking water treatment. Cold plasma technologies have been the subject of much research in recent decades for biomedical applications, including surface decontamination/sterilization of heat-sensitive materials. More recently, a new field of research called "plasma medicine" has emerged, with the treatment of cancerous tumors in particular.

Class components (lecture, labs, etc.)

Lecture and visit

Grading

MCQ

Writing of a critical analysis report of scientific articles
Presentation of the analysis in flipped classroom mode

Learning outcomes covered on the course

Protontherapy
The course will aim to learn more about this discipline through each of its dimensions. The scientific and technological dimension, in particular the particle gas pedal, the historical dimension with the mechanisms of development and maturation of this large-format "medical device", and finally the progressive integration of this mode of care in the hospital, organizational and economic scheme. The proximity of and visit to the Institut Curie Proton Therapy Center located on the Orsay Paris-Saclay campus will provide a concrete understanding of several realities of this treatment of excellence.
Non-thermal plasmas
The aim of the course is to present the physical basis of this technology, which is one of the innovative ways to strengthen the current means of fighting nosocomial infections and cancer. It is also an illustration, in the field of medical devices, of the translational research process, which is essentially interdisciplinary in nature, consisting of applying the advances obtained in the laboratory to reduce the number of unmet medical needs.

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C2. Develop in-depth competence in a scientific or sectoral field and a family of professions
C9. Act as a responsible professional. Think and act ethically.

3VS3070 – Biodesign and bio engIneering

Instructors : **Emmanuel Odic**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **22**
On-site hours (HPE) : **14,00**

Description

One objective is first of all to make students aware of the multiplicity of possibilities in the field of innovation and especially in Bio-Design. Real examples will be presented/shared by the leaders of innovative projects in the field of Bio-Design / Bio-Engineering applied to organs and their regeneration / replacement. The innovation approach will be exposed through examples describing the constraints and the development logic of these "innovative" / "research" projects and the innovation process and the concretization of ideas in "start-ups" in the MedTech / BioTech field. The goals of the innovation loop in the medical field will be illustrated through exchanges with the different actors of this loop. Finally, a first approach of the innovation financing process in France will be presented.

Quarter number

SG10

Prerequisites (in terms of CS courses)

No prerequisites

Class components (lecture, labs, etc.)

Conferences and immersion

Grading

IFSBM Terms and Conditions

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C2. Develop in-depth competence in a scientific or sectoral field and a family of professions
C9. Act as a responsible professional. Think and act ethically.

3VS3110 – Actuators for the replacement and/or assistance of health functions

Instructors : **Maya Hage Hassan**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **55**
On-site hours (HPE) : **33,00**

Description

In order to assist a motor function of a patient or an older person, through an exoskeleton, for example, a set of coordinated motorization chains can be designed, dimensioned, and implemented.
Several aspects will be addressed during this course, starting with an introductory lecture shared with the Master 2 ISMH of Paris Saclay on motor control, assistance devices, and their ergonomics.
We will first discuss general aspects of electrical actuators in the context of medical applications, and an example of dimensioning will be discussed in the context of practical work in COMSOL.
After that, a general introduction to the exoskeleton concept will be presented by the partner associated with this course, Wandercraft. A simplified model will be designed using Simulink, and a visit to the Wandercraft is also planned.

Quarter number

SG10

Prerequisites (in terms of CS courses)

none

Syllabus

Introduction lecture: Motor control, assistance devices and their ergonomics (3h)

Electric actuators course (6h)
Introduction to COMSOL modelling (1h30)
Dimensioning of an actuator in COMSOL (7h30)

Introduction to the modelling of exoskeletons (8h)

Presentation of system aspects
Presentation of the components aspects
Presentation of energy and automatic aspects

Site visit (3h)

Practical session: mechanical and motion modelling with Matlab/Simulink (3h)

Class components (lecture, labs, etc.)

Course, Visit, Labs

Grading

MCQ
Evaluation of the practical work

Resources

Course, a visit and TP

Description of the skills acquired at the end of the course

C2 Acquire and develop broad skills in a scientific or academic field and applied professional areas
C3 Act,engage,innovate within a scientific and technological environment

3VS3120 – Joint prostheses in orthopaedic surgery and traumatology

Instructors : **Emmanuel Odic**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

The main objectives of the course are : To understand the objectives of joint replacement prostheses,
Integrate anatomical issues into major joints
Be aware of the limitations and complications of these prostheses.

Quarter number

SG10

Prerequisites (in terms of CS courses)

No prerequites

Syllabus

Anatomy applied to lower limb prostheses
Lower limb prostheses
Anatomy applied to upper limb prostheses
Upper limb prostheses
Anatomy applied to spinal prostheses
Spinal disc prostheses
Reconstructive prostheses in tumor surgery
Scientific evaluation of the effectiveness and complications of prostheses
Perspectives: new technologies and prostheses

Visit of the R&D department site at CERAVER Roissy site
The design of a prosthesis on the industrial side :
Presentation of the design of a prosthesis by Ceraver

Visit of the Ceraver production site in PLAILLY

Workshops
- Implantation of a hip prosthesis
- Implantation of a knee prosthesis

Class components (lecture, labs, etc.)

Lectures and visit

Grading

IFSBM Terms and Conditions

Resources

Conferences and visits

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C2. Develop in-depth competence in a scientific or sectoral field and a family of professions
C9. Act as a responsible professional. Think and act ethically.

3VS3130 – Bioengineered Tissue and Organ Construction

Instructors : **Emmanuel Odic**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **30**
On-site hours (HPE) : **18,00**

Description

One of the fields of application of bioengineering concerns tissues and organs of living organisms. Bioengineering then aims at designing bio-artificial systems on the one hand and creating functional tissues and organs on the other hand. It paves the way for regenerative medicine that allows the repair or replacement of damaged organs by freeing itself from the constraints of organ donation and transplant rejection. Bioengineering is interdisciplinary; it integrates engineering and biological sciences with medicine and clinical practice: stem cell engineering, matrix and scaffold development, micropatterning and bioprinting, development of bioreactors for the maturation of reconstructed tissues and organs.
These innovative technologies are rapidly evolving. Their development requires bringing together researchers and engineers from biological and fundamental disciplines (physics and chemistry). The course is built on the basis of a module proposed by the doctoral school Therapeutic Innovations involving experts from different organizations such as Inserm, APHP, Institut Pasteur, INRA, and the association CellSpace.

Quarter number

SG11

Prerequisites (in terms of CS courses)

No prerequisites

Class components (lecture, labs, etc.)

Lectures

Grading

Notes for taking a step back
QCM

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C2. Develop in-depth competence in a scientific or sectoral field and a family of professions
C9. Act as a responsible professional. Think and act ethically.

3VS3140 – Organization and management of the hospital

Instructors : **Emmanuel Odic**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **34**
On-site hours (HPE) : **20,00**

Description

The objective is to enable people who are called upon to work or build projects with hospitals to have a structured vision of the hospital: the internal and external issues, the hospital setting and landscape, understand the processes, roles and responsibilities and operating methods of the hospital, through a theoretical and situational approach, perceive everything that is achieved and everything that can be done in a hospital.

Quarter number

SG11

Prerequisites (in terms of CS courses)

No prerequisites

Class components (lecture, labs, etc.)

Conferences

Grading

IFSBM Terms and Conditions

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C9. Act as a responsible professional. Think and act ethically.

3VS3150 – Healthy Connected Objects

Instructors : **Anthony Kolar**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **20**
On-site hours (HPE) : **12,00**

Description

With the display of the Internet of Things, new uses and new approaches to approach everyday life was born. This phenomenon affects all sectors of our society but some, by their nature, are more critical than others. This is the case in the medical field, whether it is helping the person or the practitioner, a means of improving living conditions or ensuring their survival, the IoT is more and more present.

But like all new technologies, this innovation is framed or even limited by legislation in order to guarantee the rights and duties specific to the medical world.
This training aims to give an overview of this sub-category of IoT by addressing the following topics:
• IoT HealthCare NetWorks
• Services and Applications
• Industrial trends
• Security in IoTs for health
• Current and future technologies
• IoT and politics
• Challenges and locks

Quarter number

SG10

Prerequisites (in terms of CS courses)

None

Syllabus

This course is organized in several conferences provided by professionals in the fields and covering a broad spectrum: technological, societal and economic.

Program:

- Introduction
  - Panorama - IoT for Healtcare
- Conferences
  - The panorama of actors, their challenges and legal aspects
  - APPLE in health
  - Digital health
    - Oncology
    - Societal issues
    - Digital pathology
    - E-Surgery
  - AI & Medical Imaging
  - Birth and life of an E-Health Start-Up

Class components (lecture, labs, etc.)

Conferences and round table

Grading

Research and analysis report

Resources

This course is given by Research Teachers, Doctors and Start-up Creators / Managers

Learning outcomes covered on the course

This course aims to focus on three specific aspects:

- Understanding the results of the appearance of connected objects in the medical world
- Discover the societal, economic and technological challenges of IoTs
- Acquire sufficient technological and legislative knowledge specific to connected objects for medicine in order to understand the constraints inherent in the design and use of such devices.

Description of the skills acquired at the end of the course

C1.1 Study a problem in its entirety, the situation as a whole. Identify, formulate and analyze a problem in its scientific, economic and human.
C1.5 Mobilize a broad scientific and technical base as part of an approach transdisciplinary.
C2.2 Transpose to other disciplinary fields, generalize knowledge.
C2.3 Identify and quickly acquire new knowledge and skills necessary in the relevant fields, whether technical, economic or other.
C2.5 Master the skills of one of the basic engineering professions (at the junior level).
C6.6 Understanding the digital economy.
C6.7 Understand the transmission of information.
C9.2 Perceive the field of responsibility of the structures to which we contribute, in integrating environmental, social and ethical dimensions.

3VS3160 – Discovery day of the medical imaging and radiotherapy plateau

Instructors : **Emmanuel Odic, Nathalie Lassau**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **22**
On-site hours (HPE) : **14,00**

Description

The objective of these immersion days is to offer a global vision, both theoretical and practical, of the medical-technical platforms of imaging and radiotherapy. It is also to present the most innovative imaging and radiotherapy modalities (PACS, image network, etc.), to explain the key issues in imaging and radiotherapy (information system and treatment traceability, and to introduce elements of quality management in radiotherapy and radioprotection.

Quarter number

SG10

Prerequisites (in terms of CS courses)

No prerequisites

Class components (lecture, labs, etc.)

Visits

Grading

IFSBM Terms and Conditions

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C9. Act as a responsible professional. Think and act ethically.

3VS3170 – Medical Technologies and Organization of Care in Perioperative Medicine

Instructors : **Emmanuel Odic**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **35**
On-site hours (HPE) : **21,00**

Description

Perioperative medicine covers all aspects of the care of the operated patient, including preparation for surgery, the transition to the operating room, the anesthesia and the surgery itself, as well as post-operative monitoring. This can be simple in most cases, allowing for outpatient care, or sometimes more complex requiring intensive human and instrumental monitoring.
This type of medicine is characterized by two apparently opposing but in reality fundamentally complementary treatment modalities: on the one hand, hyper-medicalization, characterized by the acute or even urgent nature of the diseases treated, which often involve vital prognosis within a period of time that can be counted in hours or minutes, and by the crucial role of advanced technologies (robotics, miniaturized imaging, virtual reality, machines for replacing vital functions, etc.) in daily care, whether surgical, anesthetic or resuscitation. On the other hand, these treatments are never the work of a single craftsman, but always involve a team, made up of numerous trades that must not only coexist, but above all, work together to improve the effectiveness and efficiency of care. These team-based strategies are indeed costly and deserve a reflection on the organization and human behavior, an analysis of skills, and training such as that provided by simulation sessions like those carried out by airplane pilots.

Quarter number

SG11

Prerequisites (in terms of CS courses)

No prerequisites

Class components (lecture, labs, etc.)

Lectures

Grading

IFSBM Terms and Conditions

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C9. Act as a responsible professional. Think and act ethically.

3VS3180 – Environmental health

Instructors : **Emmanuel Odic**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **22**
On-site hours (HPE) : **14,00**

Description

The aim of the module is to understand the environmental impact of healthcare systems, and to provide the main keys and levers for transforming the healthcare system and adapting to today's world. It also aims to understand the environmental issues affecting the health of populations and planetary health. In particular, the impact of climate change on the health of populations will be illustrated.
A number of lectures will be given, including AP-HP's carbon footprint, ways to decarbonize the healthcare system, and an introduction to the eco-design of healthcare.
More specifically, the following cases will be detailed:
- recycling iodine-based contrast media
- sustainable development in the surgical bloc
- responsible management of medical devices in anesthesia/intensive care

Physicians, sustainable development project managers and AP-HP transition officers, researchers, and companies (Laboratoire Guerbet, Siemens) are all involved in the module.

Quarter number
SG11

Prerequisites (in terms of CS courses)

No prerequisites

Class components (lecture, labs, etc.)

Conferences

Grading

IFSBM Terms and Conditions

Resources

Conferences

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C2. Develop in-depth competence in a scientific or sectoral field and a family of professions
C9. Act as a responsible professional. Think and act ethically.

3VS3500 – VSE HSB Project

Instructors : **Emmanuel Odic**
Department : **MENTION HEALTHCARE ET SERVICES EN BIOMÉDICAL (PARIS-SACLAY)**
Language of instruction : **FRANCAIS**
Type of course :
Campus : **CAMPUS DE PARIS - SACLAY**
Workload (HEE) : **240**
On-site hours (HPE) : **144,00**

Description

In pairs or trinomials, the students will carry out a mention project (140 hours), with the aim of producing a deliverable (software, prototype, scientific study) for an academic or industrial client in the health sector, in the fields of information, medical devices, organization of care or health systems, etc. These projects can also be proposed by students who are carrying out an entrepreneurial project.

Quarter number

SD9, SG10, SG11

Prerequisites (in terms of CS courses)

Scientific prerequisites according to the subject

Class components (lecture, labs, etc.)

The work will be carried out in priority at the School, but a partial reception at the partner's home is possible.
The students will be supervised by a tutor from the partner and followed by an academic tutor from the School.
The modalities of supervision are variable (face-to-face meetings, telephone appointments, exchange of e-mails).
The deliverables of these projects can be, for example, a process dimensioning calculation, a model, a software, a data analysis, a technico-economic study, ...

Grading

Mid-term defense (early February) and final defense (mid-April) with delivery of a report and deliverables to the client.

Resources

Computer and experimental facilities available at CentraleSupélec

Learning outcomes covered on the course

The project of mention constitutes an experience of scientific or technico-economic project management in the field of health. The scientific and technical skills mobilized with the objective of innovation are complemented by a knowledge of how to behave towards the partner as well as by methods of project management/team management.

Description of the skills acquired at the end of the course

C1. Analyze, design and build complex systems with scientific, technological, human and economic components
C2. Develop in-depth competence in a scientific or sectoral field and a family of professions

C3. Acting, undertaking, innovating in the scientific and technological environment
C4. Have a sense of value creation for your company and its customers
C6. Be comfortable and innovative in the digital world
C7. Know how to convince
C8. Leading a project, a team
C9. Act as a responsible professional. Think and act ethically.