Ph.D. Program in Information Engineering

Course Catalogue

A.Y. 2021/2022

Rev. 1.1 – 22/10/2021
Revision History

Revisions with respect to the reference version: 1.0 – 13/10/2021

Rev. 1.1 – 22/10/2021

- Identification code of all courses changed.
- Status of course “TSK 1. Python Programming for Scientific Engineering” changed from waiting for instructor confirmation to course not offered in 2021/22.
- Course “IE_BIO 4. Quantitative Neuroimaging: from Microparameters to Connectomics” added to the Catalogue. Lecture dates and hours published on the Calendar.
- Syllabus of course “IE_CSC 5. Domain-Specific Accelerators” added. Lecture dates and hours published on the Calendar.
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Coursework Requirements

The following requirements are valid for Ph.D. Students starting in October 2020 (36° cycle). In summary, Students shall take courses for a minimum of 20 credits and shall attend the seminars proposed by the Ph.D. Program, following the rules detailed below.

Important note: persisting of the COVID-related emergency may cause changes to the course and seminar schedule and consequent requirements adjustments (typically, deadline postponement). Should this happen, students will be informed in due course of the changes.

Definitions

A course is a series of lectures given by an instructor (professor or university researcher), possibly accompanied by laboratory sessions, that includes an assessment of the student knowledge (final exam, graded homework or project, etc.). A course gives credits.

A seminar, in the context of the Ph.D. Program, is typically a talk, or a series of talks, given by an academic researcher or an eminent professional, that does not include an assessment. A seminar does not give credits.

Course requirements

- Take Ph.D. courses for a minimum of 20 credits by the end of the second year.

Specific constraints to earn the minimum of 20 credits of courses:

C.1 Transversal Skills Area (TSK): at least 5 credits should come from courses belonging to the Transversal Skills area (labeled TSK in the course Summary) and to the Mathematical and Statistical Methods area (labeled IE_MSM).

C.2 Information Engineering Area (IE_*): students shall earn at least 10 credits by taking courses belonging to the Information Engineering Area (labeled IE_* in the course Summary, with * being MSM, BIO, ELE, TLC, AUT, CSC, OPT).

C.3 External Courses: up to a maximum of 5 credits may be earned by taking external courses (i.e. courses not included in this catalogue) falling in the following categories:
  - Courses appearing in the list of external courses approved by the Executive Board. The list of credited external courses is available on the Ph.D. Program main website.
  - Additional external courses might be included into the list after submission of a written request signed by the Student and his/her Supervisor. Only courses including an exam with grading are considered.
  - Courses from other Ph.D. School catalogues (provided they include a final exam with grading).
  - In order to get credit recognition for external courses, students shall obtain a certificate stating that the student attended the course and successfully passed the exam. Alternatively, the student may fill a Certification of Attendance with the course data and have it signed by the course instructor.
Seminar requirements

- Attend the seminars promoted by the Ph.D. Program (find the list on the website) during the three-year Ph.D. course.
- Attend all the lectures of the Distinguished Lecturer Series program offered by the Department during the three-year Ph.D. course.
- Attend at least two modules of the PhD Educational Week on Transferable Skills 2022.

Each first-year student must fill a tentative program of study form and upload it using the following link:

https://phd.dei.unipd.it/study-and-research-plan

within November 5th. The program of study may be subsequently modified by submitting a new form no later than June 30th of the second year. Seminars, Distinguished Lectures and PhD Educational Week modules should not be included in the program of study. Please, use the Seminar Certificate of Attendance to collect the signature of the speaker or of a member of the Executive Board attending the event.

Students are expected to attend classes regularly. Punctuality is expected both from instructors and students. Instructors have to report to the Coordinator of the Ph.D. Program students missing classes without proper excuse.

Instructors shall complete student grading within 30 days after the end of lectures and, anyway, no later than August 31st.
Class Schedule

The class schedule is embedded in the Ph.D. Program Calendar. If you have a Google account, you may visualize the class schedule through the following link:

Class Schedule of 2021/22 PhD Courses for Google Calendar

You may also visualize the class schedule using any browser through the following link:

Class Schedule of 2021/22 PhD Courses

With very few exceptions, classes meet in classrooms and meeting rooms of the Department of Information Engineering, via Gradenigo 6/A, Padova. In order to locate the rooms, you may find helpful the map of the Department buildings:

Map of the Department of Information Engineering

Please, always check the class schedule in the calendar to verify the room where the class meets.
TSK 1. Entrepreneurship and Technology-based Startups

Course Area: Transversal Skills

Credits: 5 (20 hours)

Instructors: Prof. Moreno Muffatto, Ing. Francesco Ferrati, Dipartimento di Ingegneria Industriale, Università di Padova

e-mail: moreno.muffatto@unipd.it, francesco.ferrati@unipd.it

Topics:

From the idea to the market

- Entrepreneurship attitudes
- What is a startup
- From a research project to an entrepreneurial project
- Market dimension, customers profiles and value proposition
- Development of the product/service concept

Intellectual Property Rights

- Types of IPR (patent, copyright, trademark)
- The structure of a patent application (description, claims, etc)
- Getting a patent: the patenting process (step by step)
- When to file a patent application: priority date, Patent Cooperation Treaty (PCT)
- Where to protect an invention
- Different IPR strategies

The team and the early decisions

- The creation of the founders' team
- Types and characteristics of founders' teams
- Founders' decisions and their consequences
- Frequent mistakes and suggestions deriving from experience

The economic and financial aspects of a startup

- The fundamental economic and financial operations of a technology-based startup
- The structures of the financial statements
- Income Statement, Balance Sheet, Cash Flow
- Evaluation of the value of the company
- Sources and cost of capital

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Funding a startup

- Different sources of funds: Angel Investors and Venture Capital
- Investment companies and funds: how they work
- How and what investors evaluate
- The investment agreements between investors and startups
- New ventures’ funding options

References:


Schedule and room: please, see Class Schedule

Enrollment:

To attend the course registration is compulsory by using the Moodle platform of the PhD Course in Industrial Engineering (in order to enter the Moodle platform click on “dettagli” of the course at the page http://www.cdi.dii.unipd.it/corsi). Once you are registered, if you cannot attend the course, please inform the lecturer.

Examination and grading: Attendance is required for at least 70% of the lecture hours (i.e. 14 hours). Final evaluation will be based on the discussion of a case study of a technology-based startup.
TSK 2. Python Programming for Scientific Engineering

Course Area: Transversal Skills

Credits: 5 (xx lecture hours; yy hours for hands-on-sessions)

Instructors: ...

e-mail: ...

Important note: course not offered in 2021/22
IE_MSM 1. Statistical Methods

Course Area: Information Engineering (may also be taken as Transversal Skills course)

Credits: 6 (24 hours)

Instructor: Dr. Lorenzo Finesso (formerly of CNR-IEIIT Padova)

e-mail: lorenzo.finesso@unipd.it

Aim: The course will present a small selection of statistical techniques which are widespread in applications. The unifying power of the information theoretic point of view will be stressed.

Topics:

- **Background material.** The noiseless source coding theorem will be quickly reviewed in order to introduce the basic notions of entropy and I-divergence. (a.k.a. relative entropy, Kullback-Leibler distance) between two probability measures.

- **Divergence minimization problems.** Three I-divergence minimization problems will be posed and, via examples, they will be connected with basic methods of statistical inference: ML (maximum likelihood), ME (maximum entropy), and EM (expectation-maximization).

- **Multivariate analysis methods.** The three standard multivariate methods, PCA (principal component analysis), Factor Analysis, and CCA (canonical correlations analysis) will be reviewed and their connection with divergence minimization discussed. Applications of PCA to least squares (PCR principal component regression, PLS Partial least squares). Approximate matrix factorization and PCA, with a brief detour on the approximate Nonnegative Matrix Factorization (NMF) problem. The necessary linear algebra will be reviewed.

- **EM methods.** The Expectation-Maximization method will be introduced as an algorithm for the computation of the Maximum Likelihood (ML) estimator with partial observations (incomplete data) and interpreted as an alternating divergence minimization algorithm à la Csiszár Tusnády.

- **Applications to stochastic processes.** Introduction to HMM (Hidden Markov Models). And Maximum likelihood estimation for HMM via the EM method.

References: A set of lecture notes and references will be posted on the moodle page of the course.

Schedule and room: Please, see Class Schedule.

Enrollment: Students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: Familiarity with basic linear algebra and probability.

Examination and grading: Homework assignments.
IE_MSM 2. Statistics for Engineers

Course Area: Information Engineering (may also be taken as Transversal Skills course)

Credits: 5

Number of lecture: 6 lectures, 6 hours per day – only online, Zoom required for connection

Instructors: Prof. Luigi Salmaso, Prof. Rosa Arboretti, Prof. Marta Disegna, University of Padova.

e-mail: luigi.salmaso@unipd.it, rosa.arboretti@unipd.it, marta.disegna@unipd.it

Important note: registration mandatory; if you are interested to take this class (please see website https://phd.dei.unipd.it/courses/)

Outline of lecture and lab: The course is structured into 2 on-campus lectures and a Summer School of 4 days. A total of 40 hours in-person course will be delivered.

The on-campus lectures will take place on Wednesday the 4th February 2022 and Wednesday the 11th February 2022. Classes will take place in the morning, 9am to 1pm, and in the afternoon, 2pm to 4pm for a total of 6 hours per day.

The Summer School will take place in Villa San Giuseppe, Monguelfo, Bolzano province (https://www.villasangiuseppemonguelfo.com) from Tuesday the 28th June 2022 to Friday the 1st July 2022 for a total of 28 hours. The Summer school will start at 2pm on Tuesday and will finish at 4pm on Friday.

Villa San Giuseppe offer a full board accommodation and rooms are of different size. The cost of the Summer School is €150 (for the full board accommodation to be paid on site; this expense will be refunded by the PhD Program) for the entire period.

Aim: The course is an introduction to statistical methods most frequently used for experimentation in Engineering. Lectures are planned both in the classroom and in computer lab also for an introduction to the use of the following statistical software:

- R and Rstudio, both open-source software.
- MINITAB, licensed to University of Padova.

Topics:

1. Elements of univariate statistical methods:
   a. Elements of descriptive statistics: frequency, indices of synthesis (position, variability and shape) and graphical representations (histogram, boxplot, scatterplot).
   b. Elements of probability theory: discrete and continuous probability distributions.
   c. Elements of statistical inference: sampling distributions, point and interval estimation, hypothesis testing, One-way ANOVA.
2. Linear and non-linear regression models:
   a. Simple and multiple linear regression model
   b. Logit model

3. Multivariate data analysis:
   a. Cluster Analysis: idea and steps
   c. Distance and dissimilarity matrices.
   d. Hard clustering algorithms: hierarchical clustering algorithms, non-hierarchical clustering algorithms and Bagged clustering algorithm.
   e. Fuzzy clustering algorithms: fuzzy C-means and fuzzy C-medoids.
   f. Validity indices and optimal number of clusters.
   g. Labelling and profiling the clusters: an application of suitable tests and regression models.

4. DOE: Introduction to Factorial Designs, Two level and general factorial designs. Tutorials in MINITAB.

**Examination and grading:** Attendance is required for at least 2/3 of the lecture hours. Final evaluation will be based on the discussion of a case study within the individual PhD project.

**Enrollment:** students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication). Please note that enrollment in this specific course is reserved to Students of the Ph. D. Program in Information Engineering. Students of other Ph.D. Programs please refer to their Program secretariat.

**Schedule and room:** please, see Outline of lecture and lab above or the Class Schedule.

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IE_MSM 3. Computational Inverse Problems

Course Area: Information Engineering

Credits: 5 (20 hours)

Instructor: Prof. Fabio Marcuzzi, Dept. of Mathematics, University of Padova.

e-mail: marcuzzi@math.unipd.it

Aim: We study numerical methods that are of fundamental importance in computational inverse problems. Real application examples will be given for distributed parameter systems in continuum mechanics. Computer implementation performance issues will be considered as well.

Topics:

• definition of inverse problems, basic examples and numerical difficulties.
• numerical methods for QR and SVD and their application to the square-root implementation in PCA, least-squares, model reduction and Kalman filtering; recursive least-squares; High Performance Computing (HPC) implementation of numerical linear algebra algorithms.
• regularization methods;
• underdetermined linear estimation problems and sparse recovery;
• numerical algorithms for nonlinear parameter estimation: nonlinear least-squares (Levenberg-Marquardt), back-propagation learning;
• underdetermined nonlinear estimation problems and deep learning;
• examples with distributed parameter systems in continuum mechanics: reconstruction of forcing terms and parameters estimation;

References:

[1] F. Marcuzzi "Computational Inverse Problems", lecture notes (will be posted on the moodle page of the course)


Schedule and room: please, see Class Schedule

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements:
• basic notions of linear algebra and, possibly, numerical linear algebra.
• the examples and homework will be in Python (the transition from Matlab to Python is effortless).

**Examination and grading:** Homework assignments and final test.
IE_MSM 4. Heuristics for Mathematical Optimization

Course Area: Information Engineering

Credits: 5 (20 hours)

Instructor: Prof. Domenico Salvagnin
e-mail: dominiqs@gmail.com, domenico.salvagnin@unipd.it

Aim: Make the students familiar with the most common mathematical heuristic approaches to solve mathematical/combinatorial optimization problems. This includes general strategies like local search, genetic algorithms and heuristics based on mathematical models.

Topics:
- Mathematical optimization problems (intro).
- Heuristics vs exact methods for optimization (intro).
- General principle of heuristic design (diversification, intensification, randomization).
- Local search-based approaches.
- Genetic/population based approaches.
- The subMIP paradigm.
- Applications to selected combinatorial optimization problems: TSP, QAP, facility location, scheduling.

References:

Schedule and room: please, see Class Schedule

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements:
- Moderate programming skills (on a language of choice)
- Basics in linear/integer programming.

Examination and grading: Final programming project.
IE_BIO 1. Statistical Learning for Big Data in Medicine

Course Area: Information Engineering

Credits: 5 (20 hours)

Instructor: Prof. Andrea Facchinetti (Department of Information Engineering, University of Padova), Dr. Martina Vettoretti (Department of Information Engineering, University of Padova)

e-mail: facchine@dei.unipd.it, martina.vettoretti@unipd.it

Aim: The course is intended to provide a better understanding of the methodologies used in the analysis of big data in medical applications and epidemiology.

Topics:

- Types of clinical studies (randomized clinical trials, retrospective studies, longitudinal studies), definition of exposures and main outcomes (incidence, prevalence, risk ratio, odds ratio);
- Logistic regression to link covariates to the main outcome: definition and properties, parameter estimation via maximum likelihood, coefficient interpretation, goodness of fit tests, covariate selection;
- Survival analysis: definition of lifetime, survival, and hazard functions; univariate nonparametric and parametric survival analysis; multivariate survival analysis with parametric and semiparametric (Cox) proportional hazard models;
- Practical issues related to predictive model development: dealing with missing values, dealing with unbalanced datasets, ensure model generalization;
- Hands-on: analysis of big data collected in medical research and implementation of logistic / survival models for the prediction of clinical outcomes

References:

- A set of lecture notes and a complete list of references will be made available by the Lecturer
- The Elements of Statistical Learning: Data Mining, Inference, and Prediction (Second Edition, 2009) by Trevor Hastie, Robert Tibshirani, Jerome Friedman

Schedule and room: please, see Class Schedule

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: Basics of probability theory and statistics; basics of Matlab programming.

Examination and grading: Final project consisting in the development of logistic / survival models on a given dataset.
IE_BIO 2. Advanced topics on Model Predictive Control

Course Area: Information Engineering

Credits: 5 (20 hours)

Instructors: Dr. Mattia Bruschetta, Prof. Ruggero Carli, Prof. Simone Del Favero, Department of Information Engineering, University of Padova

e-mail: mattia.bruschetta@dei.unipd.it, carlirug@dei.unipd.it, simone.delfavero@unipd.it

Aim: To provide advanced methodological tools for the application of linear and nonlinear Model Predictive Control (MPC). The course is tailored to students with a solid background on control system engineering or who have already attended basic course on MPC.

Topics:

1. Review of linear MPC, offset-free tracking and disturbance rejection.
2. Hybrid MPC. Case study: artificial pancreas with manual input
4. Learning based NMPC (LbNMPC): using learning dynamics approach based on Guassian Regression. Case study: Furuta inverted pendulum

References:


Other material and research papers will be available online for download.

Schedule and room: please, see Class Schedule

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: Linear Algebra, system theory or foundation of MPC.

Examination and grading: Homework and take home exam.
IE_BIO 3. Fluid mechanics for the functional assessment of cardiovascular devices

Course Area: Information Engineering

Credits: 5 (18 hours)

Instructor: Prof. Francesca Maria Susin, Dept. of Civil, Environmental and Architectural Engineering (DICEA)

e-mail: francescamaria.susin@unipd.it

Aim:
The course is intended to give a survey of research approaches for the assessment of cardiovascular medical devices. Emphasis will be given to methods and techniques adopted for in vitro analysis of hemodynamic performance of prosthetic heart valves.

Topics:
Review of basic fluid mechanics concepts. Fluid mechanics of prosthetic heart valves (PHVs). Pulse duplicators for in vitro testing of PHVs and mock circulation loops for pre-clinical evaluation of VADs. Experimental techniques for the assessment of PHVs. CFD for functional assessment of PHVs.

References:
Further references will be given during the course.

Schedule and room: please, see Class Schedule

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: Fundamentals of Fluid Dynamics.

Examination and grading: Homework assignment with final discussion.
IE_BIO 4. Quantitative Neuroimaging: from Microparameters to Connectomics

**Course Area:** Information Engineering  

**Credits:** 5 (20 hours)  

**Instructors:** Prof. Alessandra Bertoldo, Prof. Mattia Veronese, Department of Information Engineering, University of Padova  

**e-mail:** alessandra.bertoldo@unipd.it, mattia.veronese@unipd.it  

**Aim:** The course aims to give the methodological knowledge necessary to define a directed or non-directed brain network (compartmental models, seed-based analysis, ICA, mutual information, dynamic casual modeling) and its topographic analysis (graph theory).

**Topics:**  
- What is quantitative neuroimaging: methods to quantify PET microparameters and fMRI features (preprocessing, the role of the atlases, input/output models, compartmental models, seed based analysis, ICA);  
- Metabolic connectivity (static and dynamic): SICE methods & Non-SICE methods (Pearson, Cosine, Euclidean)  
- Network theory applied on brain connectivity  
- Hands-on: analysis of neuroimaging data to estimate functional connectivity maps and derived graph measures.

**References:** Lecture notes and a complete list of references will be made available by the Lecturers.

**Schedule and room:** please, see **Class Schedule**

**Enrollment:** students must enroll in the course using the **Enrollment Form** on the PhD Program eLearning platform (requires SSO authentication).

**Course requirements:** Basics of modeling, system identification and statistics; basics of Matlab programming.

**Examination and grading:** Final project consisting in the definition and analysis of a brain network using MRI and/or PET data.
IE_ELE 1. Diagnostics of Electron Devices

Course Area: Information Engineering

Credits: 5 (20 hours)

Instructor: Prof. Giovanna Mura, Department of Electrical and Electronic Engineering (DIEE), University of Cagliari.

E-mail: gmura@diee.unica.it

Aim: this course provides an overview of the Failure Analysis techniques for the diagnostics of electron devices. Failure analysis is the process of analyzing the failed electron devices to determine the reason for degraded performance or catastrophic failure and to provide corrective actions able to solve the problem. It is a proactive tool with three fundamental tasks: 1) Technical/scientific: 2) Technological 3) Economical. The purpose of this course is to teach what Failure Analysis should be and should do, to show how and why it often does not, to state that F.A. has Logics and has Rules.

Microscopy, in its several forms (optical, electron, scanning, transmission, emission, ionic) and tools is the playground for practical FA, and its fundamentals will be described. Device basic technology, working principle and failure physics are the other pillars for a successful study.

Several case studies will be proposed with the aim to demonstrate that if sometimes Failure Analysis looks unclear or not problem solving is merely because it was badly conducted.

Topics:
1. Reverse engineering
2. Failure modes and failure mechanisms
3. Principles and fundamental methods in Electron Microscopy
4. Methodology for the Failure Analysis


Slides

Schedule and room: please, see Class Schedule

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: Electron Devices, Microelectronics, Optoelectronics devices.

Examination and grading: Written test/presentation of a report at the end of the course.
**IE_ELE 2. Physics and Operation of Heterostructure-Based Electronic and Optoelectronic Devices**

**Course Area:** Information Engineering

**Credits:** 5 (20 hours)

**Instructors:** Prof Enrico Zanoni, Prof. Matteo Meneghini, Dr. Carlo De Santi, DEI, University of Padova.

e-mail: [zanoni@dei.unipd.it](mailto:zanoni@dei.unipd.it), [menego@dei.unipd.it](mailto:menego@dei.unipd.it), [desantic@dei.unipd.it](mailto:desantic@dei.unipd.it)

**Aim:** This course provides an introduction to the physics and operating principles of advanced electronic and optoelectronic devices based on compound semiconductors. These devices are particularly important for several applications: high electron mobility transistors (HEMTs) represent excellent devices for the realization of high frequency communication systems, radars, satellite applications, and high efficiency power converters. On the other hand, LEDs and lasers are high-efficiency monochromatic light sources, that can be used both for lighting applications (with a considerable energy saving), in the biomedical field, and in in photochemistry. Special focus will be given to Gallium Nitride (GaN) based devices, that represent the most promising devices for future power electronics applications. This course will focus on the main aspects related to the physics of heterostructures, on the recombination processes in semiconductors, on carrier transport in heterostructures, on the structure and operating principles of MESFET, HEMTs, GITs, on the trapping and reliability in compound semiconductor devices, on the operating principles of LEDs and lasers, and on parasitics and reliability in LEDs and lasers. An overview of real applications highlighting the capabilities of these devices will also be given.

**Topics:**

- physics of heterostructures, band diagrams, carrier transport in heterostructures;
- recombination processes in semiconductors; properties of compound semiconductors;
- basic structure of heterojunction transistors, MESFET, HEMT, GIT; parasitics and reliability in HEMTs, LEDs and lasers;
- operating principles of LEDs and lasers;
- methods for advanced characterization of heterojunction based devices; applications of GaN based HEMTs, LEDs and lasers;
- modeling of semiconductor-based devices

**References:**


Tae-Yeon Seong, Jung Han, Hiroshi Amano, Hadis Morko, III-Nitride Based Light Emitting Diodes and Applications, Springer 2013

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Schedule and room: please, see [Class Schedule](#)

Enrollment: students must enroll in the course using the [Enrollment Form](#) on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: Introductory course of device physics: Microelectronics, Optoelectronic and Photovoltaic Devices.

Examination and grading: Written test at the end of the course.
IE_ELE 3. Embedded Design with FPGA

Course Area: Information Engineering

Credits: 5 (20 hours)

Instructors: Dr. Andrea Stanco and Prof. Daniele Vogrig, Department of Information Engineering, University of Padova

e-mail: andrea.stanco@dei.unipd.it, vogrig@dei.unipd.it

Aim: The course aims at teaching how to practically use System-on-a-Chip (FPGA+CPU) as a potential application to academic research topics. 75% of the course will be held in a dedicated laboratory to deal with the programming of a Pynq-Z1 board.

Topics:

- Introduction to FPGA and Zynq SoC.
- Introduction to Vivado System Design environment. Time domains, time violations, metastability, system constraints.
- Introduction to SDK environment
- Information exchange between processor and programmable logic. Hardware and Software interrupts.
- Communication between SoC and the outside world.
- PYNQ (Python on Zinq) project as example of how to make easier the design embedded systems
- Case studies

References:


Other material will be pointed out in class and available online for download

Schedule and room: please, see Class Schedule

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).
**Course requirements**: Basic knowledge of digital electronics. Knowledge of program language (e.g. C/C++). No VHDL knowledge or experience on FPGAs is required.

**Examination and grading**: Homework assignments and final project.
IE_TLC 1. Introduction to Information Theory

Course Area: Information Engineering

Credits: 4

Instructor: Prof. Deniz Gunduz

e-mail: d.gunduz@imperial.ac.uk

Important note: Not offered in a.a. 2021/22
IE_TLC 2. Machine Learning for Wireless Communication Systems

Course Area: Information Engineering

Credits: 5 (20 hours)

Instructor: Dr. Paolo Dini, Senior Researcher, Centre Tecnologic de Telecomunicacions de Catalunya

e-mail: paolo.dini@cttc.es

Aim: The course will introduce the main architectures used in the design of next-generation mobile systems, together with their challenges and open issues. In particular, we focus on data-centric network scenarios and network control systems to provide broadband communications and support vertical markets. The core of the course is the application of Machine Learning (ML) tools to solve the identified networking problems. It will explained what the usage models are and what they imply in terms of stability, convergence and optimality guarantees. For this, fundamentals of Reinforcement Learning and Artificial Neural Networks will be given. Finally, several ML algorithms will be tailored for specific case studies, such as the Energy - Quality of Service trade-off and the analysis of context information (traffic demand, user mobility). The course covers Supervised, Unsupervised, Semi-Supervised and Reinforcement Learning applications to mobile networking.

Topics:

- Introduction of next-generation mobile network scenarios and architectures
  - network softwarization paradigm
  - data-centric network scenario
  - vertical markets
- Identification of machine learning tools for mobile networking issues
- Fundamentals of Reinforcement Learning
  - approximated Dynamic Programming
  - Temporal-Difference methods
  - Deep-Reinforcement Learning
- Fundamentals of Artificial Neural Network architectures
  - Multi-layer perceptrons
  - Recurrent neural networks
  - Convolutional neural networks
  - Auto-encoders
- Mobile network on-line optimization methods
  - Applications of Reinforcement Learning
- Mobile traffic characterization and modeling
  - Applications of Artificial Neural Networks

References:


Schedule and room: dates and hours to be published on the Class Schedule

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: Basic knowledge of probability theory, random processes, python scripting.

Examination and grading: Each student will develop a final project, possibly related to his/her research activity, addressing some topic presented in the Course.
IE_TLC 3. Introduction to Reinforcement Learning

Course Area: Information Engineering

Credits: 4 (15 hours)

Instructor: Dr. Juan José Alcaraz Espín, Associate Professor, Technical University of Cartagena, Spain.

e-mail: juan.alcaraz@upct.es

Aim: The course will provide an introduction to the field of reinforcement learning, covering its mathematical foundations and the description of the most relevant algorithms. The main concepts and techniques will be illustrated with Python code and application examples in telecommunications and other related areas. The students will acquire hands-on experience with the proposed assignments in which they will have to implement Python code for solving several challenges and exercises. The course will start with the basic concepts of learning in sequential decision problems, formalized in the multi-armed bandit (MAB) problem and its variants. Then, the Markov decision processes (MDPs), which generalize the MAB problem, will be introduced. The objective of reinforcement learning (RL) is to find approximate solutions to MDPs. The main RL approaches will be presented incrementally: 1) tabular methods, which are capable of addressing relatively small problems, 2) value function approximation, which allows scaling up previous algorithms to larger problems, and 3) policy gradient algorithms which follow a different scaling approach and can be used in combination with value function approximation (Actor-Critic methods).

Topics:

Unit 1. Introduction to Reinforcement Learning


Unit 4. Tabular Methods: Monte Carlo Method, Temporal Difference, Off-policy algorithms, Planning at decision time.

Unit 5. Value Function Approximation (VFA) Methods: Linear VFA, Monte Carlo with VFA, TD methods with VFA.


Unit 7 (Optional) Evolutionary Algorithms

References:


Schedule and room: dates and hours to be published on the Class Schedule.

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course Requirements: Basics of linear algebra, probability theory, Python scripting

Examination and Grading: The grading will be based on the students’ solutions to the proposed assignments.
IE_TLC 4. Information Theoretic Models in Security

**Course Area:** Information Engineering

**Credits:** 5 (20 hours)

**Instructor:** Prof. Nicola Laurenti, Department of Information Engineering

e-mail: nil@dei.unipd.it

**Important note:** waiting for instructor confirmation.
IE_AUT 1. Modeling and Simulation of Complex & Multi-Disciplinary Dynamical Systems

Course Area: Information Engineering

Credits: 4 (16 hours)

Instructor: Luca Daniel, Professor of Electrical Engineering and Computer Science, Massachusetts Institute of Technology

e-mail: luca@mit.edu

Important note: Not offered in a.a. 2021/22
IE_AUT 2. Elements of Deep Learning

Course Area: Information Engineering

Credits: 6 (24 hours)

Instructor: Dr. Gian Antonio Susto

e-mail: gianantonio.susto@dei.unipd.it

Aim: The course will serve as an introduction to Deep Learning (DL) for students who already have a basic knowledge of Machine Learning. The course will move from the fundamental architectures (e.g. CNN and RNN) to hot topics in Deep Learning research.

Topics:

- Introduction to Deep Learning: context, historical perspective, differences with respect to classic Machine Learning.
- Feedforward Neural Networks (stochastic gradient descent and optimization).
- Convolutional Neural Networks.
- Neural Networks for Sequence Learning.
- Elements of Deep Natural Language Processing.
- Elements of Deep Reinforcement Learning.
- Unsupervised Learning: Generative Adversarial Neural Networks and Autoencoders.
- Laboratory sessions in Colab.
- Hot topics in current research.

References:


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**Schedule and room:** please, see [Class Schedule](#).

**Enrollment:** students must enroll in the course using the [Enrollment Form](#) on the PhD Program eLearning platform (requires SSO authentication).

**Course requirements:** Basics of Machine Learning and Python Programming.

**Examination and grading:** Final project.
IE_AUT 3. Applied Functional Analysis and Machine Learning

Course Area: Information Engineering

Credits: 7 (28 hours)

Instructor: prof. Gianluigi Pillonetto

e-mail: giapi@dei.unipd.it

Aim: The course is intended to give a survey of the basic aspects of functional analysis, machine learning, regularization theory and inverse problems.


References:


Schedule and room: please, see Class Schedule

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).
**Course requirements:** The classical theory of functions of real variable: limits and continuity, differentiation and Riemann integration, infinite series and uniform convergence. The arithmetic of complex numbers and the basic properties of the complex exponential function. Some elementary set theory. A bit of linear algebra.

**Examination and grading:** Homework assignments and final test.
IE_AUT 4. Applied Linear Algebra

Course Area: Information Engineering

Credits: 5 (20 hours)

Instructors: Prof. Luca Schenato, Dipartimento di Ingegneria dell’informazione, Università di Padova (http://automatica.dei.unipd.it/people/schenato.html)

e-mail: schenato@dei.unipd.it

Aim: We study concepts and techniques of linear algebra that are important for applications with special emphasis on the topics: solution of systems of linear equations with particular attention to the analysis of the backward error and computational cost of the basic algorithms and matrix equation. A wide range of exercises and problems will be an essential part of the course and constitute homework required to the student.

Topics:

1. Vectors: inner products, norms, main operations (average, standard deviation, ...)
2. Matrices: matrix-vector and matrix-matrix multiplication, Frobenius norm,
3. Complexity, sparsity
4. Special matrices: Diagonal, Upper Triangular, Lower triangular, Permutation (general pair), inverse and orthogonal
5. A square and invertible: LU decomposition (aka gaussian elimination), LU-P decomposition, Cholesky decomposition
6. Ax=b via LU-P decomposition: forward and backward substitution
7. (sub)Vector spaces: definitions, span, bases (standard, orthogonal, orthonormal), dimension, direct sum, orthogonal complement, null space, orthogonal complement theorem
8. Gram-Smith orthogonalization and QR decomposition (square and invertible A, general non-square)
9. Ax=b via QR decomposition. LU-P vs QR
10. Linear maps: image space, kernel, column and row rank
11. Fundamental Theorem of Linear Algebra (Part I): rank-nullity Theorem, the 4 fundamental subspace
12. Eigenvalues/eigenvector and Shur decomposition
13. Projection matrices: oblique and orthogonal, properties
14. Positive semidefinite matrices: properties and quadratic functions square root matrix
15. Properties of A’A and AA’ and Polar decomposition
16. Singular Value Decomposition: proofs and properties
17. Pseudo-inverse: definition and relation to SVD
18. Fundamental Theorem of Linear Algebra (Part II): special orthogonal basis for diagonalization
19. Least-Squares: definition, solution and algorithms
20. Ill-conditioned problems vs stability of algorithms, numerical conditioning of algorithms, numerical conditionings

**Objectives:**

- **Theory:** formal proofs of many results (theorem-proof type problems)
- **Algorithms:** understanding of most commonly used algorithms used in MATLAB and Python for Linear Algebra
- **Implementation:** MATLAB implementation of algorithms and performance evaluation on Big Data

**References:**

*Textbooks and Internet Notes:*


**Schedule and room:** please, see [Class Schedule](#)

**Enrollment:** students must enroll in the course using the [Enrollment Form](#) on the PhD Program eLearning platform (requires SSO authentication).

**Course requirements:** A good working knowledge of basic notions of linear algebra as for example in [1]. Some proficiency in MATLAB.

**Examination and grading:** Grading is based on Homeworks, Written final exam, Short presentation based on a recent paper of Linear Algebra Algorithms for Big Data.
IE_AUT 5. Adaptive Control

Course Area: Information Engineering

Credits: 5 (20 hours)

Instructor: Prof. Andrea Serrani, The Ohio State University

e-mail: serrani.1@osu.edu

Important note: full syllabus available soon.

Schedule and room: late spring/summer 2022, lectures exact days and time will be published in Class Schedule

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).
IE_AUT 6. Causal Inference for Complex Networks

Course Area: Information Engineering

Credits: 4 (16 hours)

Instructor: Prof. Reza Arghandeh, Department of Electrical and Computer Engineering, Florida State University

e-mail: r.arghandeh@fsu.edu

Important note: course to be held in late spring/summer 2022 conditional to the possibility of prof. Arghandeh to travel to Padova

Aim:

One of the notable analytical challenges of our century is the intricate complexity of systems that shape our civilization ranging from electricity networks to computer networks to biological networks and social networks due to all interdependency and interconnectivity among them. It is near impossible to understand complex network systems behavior unless we go beyond the classic machine learning and network science and develop a casual insight into the machinery behind different networks. Nevertheless, the notable differences in forms, scopes, components, and nature of different networks, most networks follow common cause and effect principles. This course provides a selection of concepts from information theory and causality inference domains to analyze complex networks considering their inherent interdependencies. During the course, students will be familiar with use cases from electric grids, roadways, and social networks.

Topics:

1. Motivating problems in complex networked systems. i) some analytical problems in smart grids. ii) some analytical problems in smart cities.

2. Elements of Graph Theory: i) overview of graphs. ii) path, connectivity, and weighted graphs. iii) metrics for graphs.

3. Causality Inference: i) causality language ii) theory of causation and intervention iii) state-of-the-art causality inference methods

4. Causality for Complex networks i) causality methods for large scale networks ii) example applications in smart grids

References:


[3] F. Bullo, Lectures on Network Systems, CreateSpase, 2018. Class lectures and other material and research papers will be available online for download.
Schedule and room: late spring/summer 2022, lectures exact days and time will be published in Class Schedule.

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

Course requirements: familiarity with basic probability. Knowledge of network theory also helps, but it is not a requirement.

Examination and grading: a final project or a take-home exam.
IE_CSC 1. Real-Time Systems and Applications

Course Area: Information Engineering

Credits: 5 (20 hours)

Instructor: Dr. Gabriele Manduchi, Consiglio Nazionale delle Ricerche

e-mail: gabriele.manduchi@igi.cnr.it

Important note: Not offered in a.a. 2021/22
IE_CSC 2. Bayesian Machine Learning

Course Area: Information Engineering

Credits: 5 (20 hours)

Instructor: Prof. Giorgio Maria Di Nunzio

e-mail: dinunzio@dei.unipd.it

Aim: The course will introduce fundamental topics in Bayesian reasoning and how they apply to machine learning problems. In this course, we will present pros and cons of Bayesian approaches and we will develop a graphical tool to analyse the assumptions of these approaches in classical machine learning problems such as classification and regression.

Topics:

- Introduction of classical machine learning problems.
  - Mathematical framework
  - Supervised and unsupervised learning

- Bayesian decision theory
  - Two-category classification
  - Minimum-error-rate classification
  - Bayes decision theory
  - Decision surfaces

- Estimation
  - Maximum Likelihood Estimation
  - Expectation Maximization
  - Maximum A Posteriori
  - Bayesian approach

- Graphical models
  - Bayesian networks
  - Two-dimensional visualization

- Evaluation
  - Measures of accuracy

References:


**Schedule and room:** please, see Class Schedule

**Enrollment:** students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).

**Course requirements:** Basics of Probability Theory. Basics of R Programming.

**Examination and grading:** Homework assignments and final project.
IE_CSC 3. Learning from Networks

Course Area: Information Engineering
Credits: 5 (10 lectures, 2 hours each)
Instructor: Prof. Fabio Vandin
e-mail: fabio.vandin@unipd.it
Important note: Not offered in a.a. 2021/22
IE_CSC 4. **Advanced topics in scientific and parallel programming with practical application to the CAPRI HPC infrastructure**

**Course Area:** Information Engineering

**Credits:** 5 (20 hours)

**Instructor:** Giacomo Baruzzo, Department of Information Engineering, University of Padova

e-mail: giacomo.baruzzo@unipd.it

**Aim:** Provide basic skills for working on remote servers, using/developing parallel software and deploying it on a containerized computer server. The course gives basic introduction to modern computer architecture and to the most important parallel programming paradigms: Multi-threading, OpenMP, MPI and CUDA with examples (mostly Python). The course covers basic tools to access and to interact with remote servers, to manage remote resources, and to manage jobs. The course introduces principles of software containerization from the perspective of users, providing practical examples of Docker and Singularity. The concepts discussed are applied to simple case of studies involving writing and/or running parallel programs using the CAPRI HPC infrastructure (256 cores, 6TB shared RAM and 2 GPU Nvidia P100) recently acquired by the University of Padova for research activities.

**Topics:**

1. How to use a computing server (application to CAPRI)
   a. Introduction to High Performance Computing (HPC hardware and architectures, HPC software, supercomputers)
   b. Job scheduling (slurm; writing a job; running, stopping and querying status of a job)
   c. The CAPRI queuing system and policy (CAPRI hardware and architecture; access to CAPRI and projects; execution queue; how to choose queue)
2. Containerization (singularity)
   a. Overview of containerization (definition of containers and container daemon; singularity and docker software; containers vs virtual machines; advantages: re-usability and reproducibility, flexibility, efficiency; disadvantages: learning curve)
   b. Using container that have already been defined (running, stopping, and resuming containers; containers options and flags)
   c. Defining new containers (new containers from scratch; extending existing containers)
   d. Sharing containers and the container repository (browsing and adding a container to the repository; guidelines for creating and documenting containers to be shared)
3. Version control (git)
   a. Basic operations (create a git repository, staging and committing changes, repository status and history, work with branches)
   b. Advanced operations and remote repository (clone a remote repository, work with a remote repository, GUI for git, git web-based hosting services)
4. Parallel architectures and multi-process/parallel programming  
   a. Introduction to parallel programming models and architectures (basic definitions; shared vs 
      distributed memory architectures; threading: CPU and GPU; shared memory programming; 
      message passing programming; performance metrics)  
   b. Parallel programming languages and frameworks (multi-threading; OpenMP; MPI; CUDA)  
5. Hands on example (a simple parallel software for data analysis / machine learning; a simple 
   parallel software for numerical analysis; students' proposals)  

References:  
     Pearson Education.  
   • Ad-hoc material by Lecturer  

Schedule and room: please, see Class Schedule  

Course requirements: Basics usage of tools for run/develop of scientific software (preferable unix 
platforms)  

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program 
eLearning platform (requires SSO authentication).  

Examination and grading: Each student must produce a small parallel and containerized software 
(either predefined or custom built container) related to her/his research field. Each student can 
either a) write a simple parallel software with one of the programming paradigm presented during 
the course using a language of choice or b) choose a (possibly parallel) software typically used in the 
research activity. Containerized software must run on the CAPRI server.
IE_CSC 5. Domain-Specific Accelerators

Course Area: Information Engineering

Credits: 5 (20 hours)

Instructor: Prof. Carlo Fantozzi, DEI, University of Padova.

e-mail: carlo.fantozzi@unipd.it

Aim: The hitting of fundamental limits in computer hardware technology, at a time when the needs for computing performance and efficiency are increasing, is driving a shift from general-purpose processors to domain-specific accelerators (DSAs). This course will examine how the phenomenon is occurring by analyzing a number of DSAs at different levels: architectural, algorithmic, and software. The course will also explore whether DSAs can be effective for computations not originally intended by their designers. The course will give students, regardless of their research specialization, an elemental understanding of a key ongoing event in computer design, and will provide heavy users of computer systems with valuable elements to decide how to accelerate their scientific computations.

Topics:

- Introduction to DSAs. Applications. Advantages and challenges.
- Survey of DSAs (e.g., NVIDIA’s Tensor Cores v1-v3, Google’s Tensor Processing Units v1-v4, Intel’s VNNI and AMX). DSAs implemented on FPGAs.
- Towards the design of algorithms and software for DSAs: computational models, software APIs.
- From algorithms to software: case studies in linear algebra (matrix multiplication) and integral transforms (convolution).

References:

No comprehensive book on DSAs has been published yet. The following references provide an overview of the topics covered in the course. Full references will be made available to students during lectures.


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Course requirements:

- Computer Architecture (intermediate knowledge).
- C/C++ programming (basic knowledge).
- Design and Analysis of Algorithms (basic knowledge).
- Microelectronics (a basic knowledge helps, but it is not mandatory).

Examination and grading: Each student must propose and turn in a survey report, or a software project, related to the material covered in class and exploring some architecture, algorithm, or application of DSAs. The final mark will be based on the grading of the report/project, with a small modifier to take class participation into account. Each student is encouraged to propose a report/project related to her/his research area.

Schedule and room: days and time will be published in Class Schedule

Enrollment: students must enroll in the course using the Enrollment Form on the PhD Program eLearning platform (requires SSO authentication).
IE_OPT 1. Communicating using quantum entanglement: teleportation and the Quantum Internet

**Course Area:** Information Engineering

**Credits:** 4 (16 hours)

**Instructor:** Prof. Paolo Villoresi, DEI and Padua Quantum Technologies Research Center, University of Padova.

**e-mail:** paolo.villoresi@dei.unipd.it

**Important note:** Not offered in a.a. 2021/22
## Alphabetical List of Course Instructors

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