Graduate School in Information Engineering: Ph.D. program
Department of Information Engineering
University of Padova

Course Catalogue
2015-2016

Requirements for Ph.D. Students of the Graduate School of Information Engineering:

1. Students are required to take courses from the present catalogue for *a minimum* of 80 hours (20 credits) during the first year of the Ph.D. program.
2. Students are required to take for credit *at least* one out of the following three basic courses "Applied Functional Analysis", "Applied Linear Algebra", and "Statistical Methods" during the first year of the Ph.D. program. Moreover, the other two courses are *strongly recommended* to all students.
3. After the first year, students are *strongly encouraged* to take courses (possibly outside the present catalogue) for at least 10 credits (or equivalent) according to their research interests.

Students are requested to enroll in each course they intend to take at least one month before the class starts. To enroll, it is sufficient to send an e-mail message to the secretariat of the school at the address `calore@dei.unipd.it`

Students are expected to attend classes regularly. Punctuality is expected both from instructors and students.

Instructors have to report to the Director of Graduate Studies any case of a student missing classes without proper excuse.

In addition to the courses listed in this catalogue the Graduate School will promote and organize additional courses and series of lectures, of potential interest to PhD Students, which however will not be valid for credits; these will be advertised through the Graduate School webpage (see the Seminars and Seasonal Schools *section on the web page* `http://www.dei.unipd.it/en/phd`*) as well as using the PhD Students' mailing list.*

Contents

1 Advanced Topics in Computational Biology

Instructor: Prof. Fabio Vandin, e-mail: `vandinfa@cs.brown.edu`

Aim: To provide the students with an understanding of the computational problems that arise in selected areas of computational biology, and of the state-of-the-art methods to solve such problems. The course focuses on problems that arise in the analysis of high-throughput biological datasets.

Topics:

- Mutation Detection from Sequencing Data: sequencing technologies, the mutation detection problem, algorithms for mutations detection;
- Mutations and Diseases: finding single mutations associated with diseases; interaction networks and groups of mutations associated with diseases; *de novo* discovery of groups of mutations associated with diseases;
- Genetic Heterogeneity: genetic heterogeneity in populations and diseases; genetic heterogeneity and sequencing technologies; detecting genetic heterogeneity from sequencing data; reconstructing the evolution of cancer genomes;
- Inferring Haplotypes from Sequencing Data: inferring haplotype frequencies in populations; haplotype assembly from sequencing data.

References: The following articles provide basic background material:

[1] L. Ding, M. C. Wendl, J. F. McMichael, and B. J. Raphael. Expanding the computational toolbox for mining cancer genomes. *Nat. Rev. Genet.*, 15(8):556–70, 2014.

[2] M. Meyerson, S. Gabriel, and G. Getz. Advances in understanding cancer genomes through second-generation sequencing. *Nat. Rev. Genet.*, 11(10):685–96, 2010.

[3] R. Schwartz. Theory and algorithms for the haplotype assembly problem. *Communications in Information & Systems*, 10(1):23–38, 2010.

[4] W. W. Soon, M. Hariharan, and M. P. Snyder. High-throughput sequencing for biology and medicine. *Mol. Syst. Biol.*, 9:640, 2013.

Additional research articles for the specific topics will be made available on the course website.

Time table: Course of 20 hours (1 lecture per week, 2 hours per lecture). Class meets every Tuesday from 2:30pm to 4:30pm. First lecture on Tuesday, October 13, 2015. Additional Lecture on Friday, December 11th 2015, from 10:30am to 12:30pm. Room DEI/G, 3-rd floor, Dept. of Information Engineering, via Gradenigo Building.

Course requirements: basic knowledge of algorithms; basic knowledge of probability. (No biology background is assumed; necessary background will be introduced in lectures and reading.)

Examination and grading: Each student is required i) to present and lead the discussion of one or more research paper in class, and ii) to submit short reviews of the papers before they are presented and discussed in class. The grade is based on i) participation in class, ii) paper presentations, and iii) paper reviews.

2 Applied Functional Analysis and Machine Learning

Instructor: Prof. G. Pillonetto, Dept. Information Engineering, University of Padova, 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.

Topics:

1. *Review of some notions on metric spaces and Lebesgue integration*: Metric spaces. Open sets, closed sets, neighborhoods. Convergence, Cauchy sequences, completeness. Completion of metric spaces. Review of the Lebesgue integration theory. Lebesgue spaces.

2. *Banach and Hilbert spaces*: Normed spaces and Banach spaces. Finite dimensional normed spaces and subspaces. Compactness and finite dimension. Bounded linear operators. Linear functionals. The finite dimensional case. Normed spaces of operators and the dual space. Weak topologies. Inner product spaces and Hilbert spaces. Orthogonal complements and direct sums. Orthonormal sets and sequences. Representation of functionals on Hilbert spaces. Hilbert adjoint operator. Self-adjoint operators, unitary operators.

3. *Compact linear operators on normed spaces and their spectrum*: Spectral properties of bounded linear operators. Compact linear operators on normed spaces. Spectral properties of compact linear operators. Spectral properties of bounded self-adjoint operators, positive operators, operators defined by a kernel. Mercer Kernels and Mercer's theorem.

4. *Reproducing kernel Hilbert spaces, inverse problems and regularization theory*: Representer theorem. Reproducing Kernel Hilbert Spaces (RKHS): definition and basic properties. Examples of RKHS. Function estimation problems in RKHS. Tikhonov regularization. Basic concepts of convex analysis. Primal and dual formulation of loss functions. Regularization networks. Support vector regression and classification. Support vector classification.

Course requirements:

1. The classical theory of functions of real variable: limits and continuity, differentiation and Riemann integration, infinite series and uniform convergence.
2. The arithmetic of complex numbers and the basic properties of the complex exponential function.
3. Some elementary set theory.
4. A bit of linear algebra.

All the necessary material can be found in W. Rudin's book Principles of Mathematical Analysis (3rd ed., McGraw-Hill, 1976). A summary of the relevant facts will be given in the first lecture.

References:

[1] W. Rudin. Real and Complex Analysis, McGraw Hill, 2006
[2] E. Kreyszig. Introductory Functional Analysis with Applications, John Wiley and Sons , 1978
[3] G. Wahba. Spline models for observational data. SIAM, 1990
[4] C.E. Rasmussen and C.K.I. Williams. Gaussian Processes for Machine Learning. The MIT Press, 2006
[5] R.T. Rockafellar. Convex analysis. Princeton University Press, 1996

Time table: Course of 28 hours (2 two-hours lectures per week): Classes on Tuesday and Thursday, 10:30 - 12:30. First lecture on Tuesday October 13th, 2015. Sala Riunioni 318 DEI/G 3-rd floor, via Gradenigo 6).

Examination and grading: Homework assignments and final test.

3 Fluid mechanics for the functional assessment of cardiovascular devices

Instructor: Prof. Francesca Maria Susin, Dept. ICEA, University of Padua, 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 and total artificial heart.

Topics: Review of basic fluid mechanics concepts. Fluid mechanics of prosthetic heart valves (PHVs) and ventricular assist devices (VADs). 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 and VADs performance. CFD for functional assessment of PHVs and VADs.

References:

[1] M. Grigioni, C. Daniele, G. D'Avenio, U. Morbiducci, C. Del Gaudio, M. Abbate and D. Di Meo. Innovative technologies for the assessment of cardiovascular medical devices: state of the art techniques for artificial heart valve testing. *Expert Rev. Medical Devices*, 1(1) : 81-93, 2004.

[2] K.B. Chandran, A.P. Yoganathan and S.E. Rittgers. Biofluid Mechanics: the uman circulation. CRC Press, Boca Raton, FL, 2007.

[3] A.P. Yoganathan, K.B. Chandran and F. Sotiropoulos. Flow in prosthetic heart valves: state of the heart and future directions. *Annals of Biomedical Engineering*, 33(12) : 1689-1694, 2005.

[4] A.P. Yoganathan, Z. He and S. Casey Jones. Fluid mechanics of heart valves.

[5] A.P. Yoganathan and F. Sotiropoulos. Using computational fluid dynamics to examine the hemodynamics of artificial heart valves. *Business briefing: US cardiology 2004*: 1-5, 2004.

[6] V. Barbaro, C. Daniele and M. Grigioni. Descrizione di un sistema a flusso pulsatile per la valutazione delle protesi valvolari cardiache. ISTISAN Report 91/7, Rome, Italy, 1991 (in Italian).

[7] M. Grigioni, C. Daniele, C. Romanelli and V. Barbaro. Banco di prova per la caratterizzazione di dispositivi di assistenza meccanica al circolo. ISTISAN Report 03/21, Rome, Italy, 2003 (in Italian).

[8] M.J. Slepian, Y. Alemu, J.S. Soares. R.G. Smith, S. Einav and D. Bluestein. The Syncardia total artificial heart: in vivo, in vitro, and computational modeling studies. *Journal of Biomechanics*,46 (2013): 266-27, 2013.

Time table: Course of 16 hours. Lectures (2 hours) on Wednesday 10:30 - 12:30. Starting on Wednesday, Oct. 14, 2015 and ending on Wednesday, Dec. 2, 2015. Room DEI/G, 3-rd floor, Dept. of Information Engineering, via Gradenigo Building.

Course requirements: Fundamentals of Fluid Dynamics.

Examination and grading: Homework assignment with final discussion.

4 The FFT and its use in digital signal processing

Instructor: Prof. S. Pupolin, Dept. Information Engineering, University of Padova, e-mail: `pupolin@dei.unipd.it`

Aim: The course is intended to give a survey of the basic aspects of signal domains and the effects in digital signal processing in terms of signal distortion.

Topics:

- Review of some notions on Fourier Transform in different time domains (continuous and discrete; aperiodic and periodic). The FFT.
- Definitions and properties of signal energy, convolution, correlation in the time domains and their Fourier transforms
- Signal transformations. Linear transformations. Elementary transformations: sampling and interpolation. Up- and Down-Periodization
- Numerical computation of the Fourier transform of a continuous-time finite energy signal via FFT
- Numerical computation of the convolution (correlation) of two continuous-time finite energy signals via FFT.
- Bandlmited continuous time signal filtering: from analog filters to a mix of analog and digital filters.
- Example of applications: OFDM modulation and cyclic prex.
- Channel estimation in OFDM systems
- Estimate of power spectrum for finite power signals. From definitions to numerical computation.
- FFT output SNR for a quantized input signal. Discussion

References:

All the necessary material can be found in G. Cariolaro book: "Unified Signal Theory", (Springer-Verlag, London 2011).

Time table: 20 hours, 5 credits. Class meets every Monday and Friday from 10:30 to 12:30. First lecture on Monday, October 12-nd, 2015. Room 318 DEI/G (3-rd oor, Dept. of Information Engineering, via Gradenigo Building).

Course requirements: Basic knowledge of signals and systems.

Examination and grading: Homeworks and final exam.

5 Mathematical modeling of cell Biology

Instructor: Prof. Morten Gram Pedersen, Department of Information Engineering, University of Padova, e-mail: `pedersen@dei.unipd.it`

Aim: The aim of this course is to provide an introduction to commonly used mathematical models of cellular biology. At the end of the course, the students should be able to build models of biological processes within the cell, to simulate and analyze them, and to relate the results back to biology. The focus will be on electrical activity and calcium dynamics in neurons and hormone-secreting cells, but will also discuss models of other cellular processes occurring in other cell types.

Topics: Biochemical reactions; Ion channels, excitability and electrical activity; Calcium dynamics; Intercellular communication; Spatial and stochastic phenomena (if time allows); Contractions in muscles; Circadian rhythms; Qualitative analysis of nonlinear differential equations.

References: The following books will provide the core material, which will be supplemented by research articles:

1. C.P. Fall, E.S. Marland, J.M. Wagner, J.J. Tyson. *Computational Cell Biology.* Springer, NY, USA (2002).
2. J. Keener, J. Sneyd: *Mathematical Physiology.* Springer, NY, USA (2004).

Time table: Course of 20 hours (2 two-hours lectures per week). Class meets every Monday and Wednesday from 14:30 to 16:30. First lecture on Monday, October 12, 2015. Room DEI/G, 3-rd floor, Dept. of Information Engineering, via Gradenigo Building.

Course requirements: Basic courses of linear algebra and ODEs. Basic experience with computer programming. Knowledge of cellular biology is not required.

Examination and grading: Final project.

6 Information-theoretic Methods in Security

Instructor: Prof. Nicola Laurenti, Department of Information Engineering, Univ. of Padova, e-mail: `nil@dei.unipd.it`

Aim: The class aims at providing the students with an information theoretic framework that will allow formal modeling, understanding of the fundamental performance limits, and derivation of unconditionally secure mechanisms for several security-related problems.

Topics:

- *The Holy Grail of perfect secrecy.* Shannon's cipher system. Perfect secrecy. Ideal secrecy. Practical secrecy. The guessing attack.
- *Secrecy without cryptography.* The wiretap channel model. Rate-equivocation pairs. Secrecy rates. Secrecy capacity for binary, Gaussian and fading channel models.
- *Security from uncertainty.* Secret key agreement from common randomness on noisy channels. Information theoretic models and performance limits of quantum cryptography.
- *Who's who?* An information theoretic model for authentication in noisy channels. Signatures and fingerprinting.
- *The gossip game.* Broadcast and secrecy models in multiple access channels. The role of trusted and untrusted relays.
- *Secrets in a crowd.* Information theoretic secrecy in a random network with random eavesdroppers. Secrecy graphs and large networks secrecy rates.
- *A cipher for free?* Information theoretic security of random network coding.
- *The jamming game.* Optimal strategies for transmitters, receivers and jammers in Gaussian, fading and MIMO channels.
- *Alea iacta est.* Secure and true random number generation. Randomness extractors and smooth guessing entropy.

- *Writing in sympathetic ink.* Information theoretic models of steganography, watermarking and other information hiding techniques.
- *Leaky buckets and pipes.* Information leaking and covert channels. Timing channels.
- *The dining cryptographers.* Privacy and anonymity. Secure multiparty computation.
- *Information theoretic democracy.* Privacy, reliability and verifiability in electronic voting systems.
- *The Big Brother.* An information theoretic formulation of database security: the privacy vs utility tradeoff.

References:

- Y. Liang, H.V. Poor, and S. Shamai (Shitz), *Information Theoretic Security,* Now, 2007.
- M. Bloch, J. Barros, *Physical-Layer Security: from Information Theory to Security Engineering* Cambridge University Press, 2011.
- A short list of reference papers for each lecture will be provided during class meetings.

Time table: Course of 20 hours. Class meets every Wednesday and Friday from 14:30 to 16:30. First lecture on Wednesday, January 13th, 2016. Room DEI/D, 1st floor, Dept. of Information Engineering, via Gradenigo Building.

Course requirements: Basic notions of Information Theory (e.g., those from the *Telecomunicazioni* class in the *Corso di Laurea in Ingegneria dell'Informazione*)

Examination and grading: Each student (or a small group) must submit a project, and grading will be based on its evaluation. Students are encouraged to work from an information theoretic point of view on a security problem related to their research activities.

7 Inverse Problems in Imaging

Instructor: Prof. P. Favaro, University of Bern , e-mail: `paolo.favaro@iam.unibe.ch`

Aim: The course provides an introduction to inverse problems in image processing, such as denoising, deblurring, and blind deconvolution. The main focus is to present analytical and numerical tools for solving inverse problems and to illustrate connections to several other bilinear problems in imaging, such as independent component analysis, dictionary learning/sparse coding, and matrix factorization.

Topics:

- *The fundamentals of inverse problems*: image formation models, ill-posedness and ill-conditioning, denoising and deblurring problems, a-priori information, regularization techniques, a primer on numerical solvers.
- *The Bayesian formulation and methodologies*: generative models, image priors, inference methods (e.g., Conditional Mean, Maximum a Posteriori)
- *Numerical methods*: a primer on convex optimization, descent algorithms, the Primal-Dual method, Expectation-Maximization, Variational Bayes, Majorization Minimization.
- *Advanced problems and techniques in imaging*: sparsity-based reconstructions, total variation denoising and deblurring, blind deconvolution, relations to other bilinear problems in imaging.

References:

[1] M. Bertero and P. Boccacci, *Introduction to Inverse Problems in Imaging*, Inst. of Physics Publications 1998.

[2] S. Boyd and L. Vandenberghe, *Convex Optimization*, Cambridge University Press 2004.

[3] R. T. Rockafellar, *Convex analysis*, Princeton University Press 1996.

[4] C. M. Bishop, *Pattern Recognition and Machine Learning*, Springer 2012.

[5] A. Chambolle and T. Pock, *A first-order primal-dual algorithm for convex problems with applications to imaging*, Journal of Mathematical Imaging and Vision, 40(1), 120-145, 2011.

[6] D. Wipf and H. Zhang, *Revisiting Bayesian Blind Deconvolution*, Energy Minimization Methods in Computer Vision and Pattern Recognition, 40-53, 2013.

[7] T. Chan and C. K. Wong, *Total variation blind deconvolution*, IEEE Transactions on Image Processing, 7(3), 370-375, 1998.

[8] D. Perrone and P. Favaro, *Total variation blind deconvolution: The devil is in the details*, Computer Vision and Pattern Recognition, 2909?2916, 2014.

Presentation material will be provided at the course and will be available on the course website together with additional research articles and books.

Time table: Course of 16 hours. Class meets every Tuesday and Thursday from 14:30 to 16:30. First lecture on Tuesday, January 12, 2016. Room DEI/G, 3-rd floor, Dept. of Information Engineering, via Gradenigo Building.

Course requirements: Basic notions of probability theory, linear algebra, calculus and differential equations, knowledge of computing programming using Matlab.

Examination and grading: A short programming assignment (30% of the final grade) and a final exam (70% of the final grade).

8 Bayesian Machine Learning

Instructor: 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 practical problems.

Topics:

- Introduction of classical machine learning problems.
  - Mathematical framework
  - Supervised and unsupervised learning
- Bayesian decision theory
  - Two-category classification
  - Minimum-error-rate classification
  - Bayes risk
  - Decision surfaces
- Estimation
  - Maximum Likelihood Estimation
  - Maximum A Posteriori
  - Bayesian approach
- Graphical models
  - Bayesian networks
  - Two-dimensional probabilistic model
- Evaluation
  - Measures of accuracy
  - Statistical significance testing

References:

[1] J. Kruschke, *Doing Bayesian Data Analysis: A Tutorial Introduction With R and Bugs*, Academic Press 2010

[2] Christopher M. Bishop, *Pattern Recognition and Machine Learning (Information Science and Statistics)*, Springer 2007

[3] Richard O. Duda, Peter E. Hart, David G. Stork, *Pattern Classification (2nd Edition)*, Wiley-Interscience, 2000

[4] Yaser S. Abu-Mostafa, Malik Magdon-Ismail, Hsuan-Tien Lin, *Learning from Data*, AMLBook, 2012
(supporting material available at http://amlbook.com/support.html)

[5] David J. C. MacKay, *Information Theory, Inference and Learning Algorithms*, Cambridge University Press, 2003
(freely available and supporting material at http://www.inference.phy.cam.ac.uk/ma

[6] David Barber, *Bayesian Reasoning and Machine Learning*, Cambridge University Press, 2012
(freely available at http://web4.cs.ucl.ac.uk/staff/D.Barber/pmwiki/pmwiki.php?n=

[7] Kevin P. Murphy, *Machine Learning: A Probabilistic Perspective*, MIT Press, 2012
(supporting material http://www.cs.ubc.ca/ murphyk/MLbook/)

Time table: Course of 20 hours. Tentative schedule: Class meets every Thursday and Friday from 11:30 to 13:30. First lecture on Thursday, 14th January, 2016. Room DEI/G, 3-rd floor, Dept. of Information Engineering, via Gradenigo Building.

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

Examination and grading: Homework assignments and final project.

9 Real-Time Systems and applications

Instructor: Prof. Gabriele Manduchi, Consiglio Nazionale delle Ricerche
e-mail: `gabriele.manduchi@igi.cnr.it`

Aim: The course will provide an insight in the realm of real-time system. Knowledge in this field is normally fragmented and scattered among different engineering disciplines and computing sciences, and the the aim of the course is present aspects related to theory and practice in a way which is holistic enough to prepare graduates to embark on the development of real-time systems, frequently complex and imposing safety requirements. For this reason, after presenting in the first part of the course a surveys of related topics, including scheduling theory and real-time issues in operating systems, the control system of a Nuclear Fusion experiment will be presented as Use Case and analyzed in the second part of the course.

Topics:

- Concurrent Programming Concepts: the role of parallelism and multi-threading, deadlocks, interprocess communication, network communication.
- Real-time scheduling analysis:task-based scheduling, schedulability analysis based on utilization, schedulability analysis based on response time analysis, task interaction and blocking.
- Internal structures and operating principles of Linux real-time extensions.
- Data Acquisition systems: general concepts and architectures.
- An introduction of massive parallel operation in real-time applications using GPUs.
- Analysis of a real-time control system for nuclear fusion experiment.

References:

[1] I C Bertolotti, G Manduchi. Real-Time Embedded Systems. Open Source Operating Systems Perspective. CRC Press, 2012

[2] G C Buttazzo. Hard Real-Time Computing Systems. Predictable Scheduling Algorithms and Applications. Springer 2005.

Time table: Course of 20 hours. Class meets every Tuesday and Thursday from 8:30 to 10:30. First lecture on Tuesday, January 19, 2016. Room DEI/G (3-rd floor, Dept. of Information Engineering, via Gradenigo Building).

Course requirements: Basic knowledge of Operating System concepts.

Examination and grading: Each student will develop a case study, possibly related to his/her own research activity, addressing some topic presented in the course.

10 Tissue Engineering: Principles and Applications

Instructor: Prof. Andrea Bagno, Department of Industrial Engineering, University of Padova. e-mail: `andrea.bagno@unipd.it`

Aim: The course will provide the basic knowledge of materials and methods for tissue engineering (TE) techniques. The course will also present some practical applications with regard to the production of engineered tissues.

Topics:

1. Fundamentals of TE.
2. Engineering biomaterials for TE.
3. Biomimetic materials.
4. Regeneration templates.
5. TE of biological tissues (cartilage, hearth valves, bone).

References:

[1] B. Palsson, J.A. Hubbel, R. Plonsey, J.D. Bronzino (Eds). Tissue engineering. CRC Press, Boca Raton, 2003.

[2] K.C. Dee, D.A. Puleo, R. Bizios. An introduction to tissue-biomaterials interactions. Wiley, Hoboken, New Jersey, 2002.

[3] J.B. Park, J.D. Bronzino, Biomaterials. CRC Press, Boca Raton, 2003.

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

Time table: Course of 16 hours (2 two-hours lectures per week). Classes on Monday and Wednesday, 10:30 – 12:30. First lecture on Monday, January 25, 2016. Meeting Room DEI/G (3-rd floor, Dept. of Information Engineering, via Gradenigo Building).

Course requirements: Basic courses of chemistry, biology and physiology, biomaterials.

Examination and grading: Homework assignments and final test.

11 Computational Inverse Problems

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. Computer implementation performance issues will be considered also.

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;
- regularization methods;
- numerical algorithms for nonlinear parameter estimation: Gauss-Newton, Levenberg-Marquardt;
- examples with distributed parameter systems;
- HPC implementations.

References:

[1] F.Marcuzzi "Analisi dei dati mediante modelli matematici", http://www.math.unipd.it/~marcuzzi/MNAD.html

Time table: Course of 16 hours (2 two-hours lectures per week): Classes on Monday and Wednesday, 10:30 - 12:30. First lecture on Monday February 22th, 2016. Room DEI/G, 3-rd floor, Dept. of Information Engineering, via Gradenigo Building.

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.

12 Applied Linear Algebra

Instructors: Prof. Tobias Damm, Technische Universität Kaiserslautern, Germany,
e-mail: `damm@mathematik.uni-kl.de`. Prof. Michael Karow, Technische Universität Berlin, e-mail: `karow@math.tu-berlin.de`

Aim: We study concepts and techniques of linear algebra that are important for applications with special emphasis on the topics *low rank approximation* and *matrix equations and inequalities*. A wide range of exercises and problems will be an essential part of the course and constitute homework required to the student.

Topics:

1. Review of some basic concepts of linear algebra and matrix theory
2. The singular value decomposition and applications
3. Krylov subspaces
4. Matrix equations and matrix inequalities
5. Sylvester and Lyapunov equations, Riccati equation, linear matrix inequalities (LMIs)

References:

[1] Gilbert Strang's linear algebra lectures, from M.I.T. on You Tube

[2] Notes from the instructors

Time table: Course of 16 hours.

- First lecture on March, Monday 21st 4:30 am
- Second Lecture on March, Wednedsday 23rd, 2.30 pm
- All other 6 lectures on Wednesday (2.30 pm) and Friday (10.30 am) starting from March, Wednesday 30th 2016

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 or a written examination or both.

13 Physics and operation of heterostructure-based electronic and optoelectronic devices

Instructors: Proff. G. Meneghesso, M. Meneghini, Dept. Information Engineering, University of Padova,
e-mail: gauss@dei.unipd.it, menego@dei.unipd.it
G. Curatola, Infineon Technologies AG, Villach, Austria,
e-mail: Gilberto.Curatola@infineon.com

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:

1. physics of heterostructures, band diagrams, carrier transport in heterostructures;

2. recombination processes in semiconductors;

3. properties of compound semiconductors;

4. basic structure of heterojunction transistors, MESFET, HEMT, GIT;

5. parasitics and reliability in HEMTs, LEDs and lasers;

6. operating principles of LEDs and lasers;

7. methods for advanced characterization of heterojunction based devices;

8. applications of GaN based HEMTs, LEDs and lasers;

References:

[**1**] Umesh Mishra, Jasprit Singh, Semiconductor Device Physics and Design, Springer, 2008

[**2**] Ruediguer Quay, Gallium Nitride Electronics, Springer 2008.

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

Time table: Course of 20 hours (2 two-hours lectures per week): Classes on Monday 14:30 - 16:30 and Thursday, 16:30 - 18:30. First lecture on Monday March 14, 2016. (This is a tentative schedule)

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

Examination and grading: Written test at the end of the course

14 Digital Processing of Measurement Information

Instructor: prof. Claudio Narduzzi – Department of Information Engineering, University of Padua e-mail: `claudio.narduzzi@unipd.it`

Aim: provide tools and methods for advanced analysis and accuracy assessment of measurement information obtained from experimental data.

Topics:

- uncertainty, quantisation and the additive noise stochastic model: a reappraisal
- characterisation of digitisers and data acquisition systems
- signal processing algorithms in measurement: statistical properties of discrete Fourier transform-based spectral estimators, least squares regression and the Cramer-Rao bound
- compensation of measurement system dynamics: dealing with inverse problems and ill-posedness
- an application of multi-resolution analysis in measurement - characterization of clock stability
- model-based measurement and compressive sensing
- evaluation of uncertainty in measurement: the probability-based approach and its recent developments

References:
Lecture notes and selected reference material will be handed out during the course.

Time table: Course of 16 hours.

Class meets every Tuesday and Friday from 10:30 to 12:30. First lecture on Tuesday, April 26th, 2016. Meeting Room 3rd floor, Dept. of Information Engineering, via Gradenigo Building (DEI/G).

Course requirements: no specific requirement.

Examination and grading: report on assigned homework.

15 Physical models for the numerical simulation of semiconductor devices

Instructor: Prof. Giovanni Verzellesi, Dipartimento di Scienze e Metodi dell'Ingegneria, University of Modena and Reggio Emilia.
e-mail: giovanni.verzellesi@unimore.it
web: http://www.dismi.unimore.it/index.php?q=verzellesi

Aim: This course is intended to provide 1) basic knowledge and understanding of charge transport in semiconductors and on the physical models adopted in numerical device simulators, 2) ability to simulate a GaN-based HEMT by using a commercial device simulator.

Topics: The course will cover the following topics:

a) Charge transport in semiconductors: Boltzmann transport equation, momentum method, hydrodynamic model, drift-diffusion model, drift-diffusion model for non-uniform semiconductors, models for simulation of nano-scale devices. Technology CAD: input and output data of device simulators, discretization of drift-diffusion equations, boundary conditions, physical models (mobility, generation-recombination effects, deep levels).

b) Case study: simulation of an AlGaN/GaN HEMT. Simulation of DC characteristics, AC capacitances and pulse-mode behavior. Trap-related effects.

References: M. Lundstrom, *Fundamentals of carrier transport*, Modular Series on Solid State Devices vol. X, Addison-Wesley Publ. Company, ISBN 0-201-18436-2, 1992. K. Hess, *Advanced theory of semiconductor devices*, IEEE Press, ISBN 0-7803-3479-5, 2000. D. Vasileska, S.M. Goodnick, G. Klimeck, *Computational electronics: semiclassical and quantum device modeling and simulation*, CRC Press, ISBN 978-1420064834, 2010.

Time table: Course of 20 hrs (4 hours per week). Lessons will be in April/May 2016, Thursday 14:00-16:00, Friday 9:00 - 11:00. First Lesson

Thursday April 28, 2016.

Course requirements: Background at a graduate level on semiconductor devices.

Examination and grading: Final LAB report.

16 Brain-Computer Interface for Neurorobotics

Instructor: Dr. Luca Tonin, e-mail: `luca.tonin@dei.unipd.it`

Aim: The course aims to introduce doctoral students to the Brain-Computer Interface (BCI) field, in particular applied to Neurorobotics. The course will provide advanced tools and methodologies for analyzing and decoding brain signals and for translating them into actual actions of external actuators. Multidisciplinary topics will be presented in order to cover the different parts that compose standard BCI systems: methods for processing neurophysiological signals, tools for machine learning and decision making, topics for control strategies of robotic devices. Each topic will be faced from the theoretical and practical point of view, by means of frontal lectures and exercises to be solved both during classes and as homeworks (in Matlab or C/C++). The final project will focus on the implementation of an online BCI system to mind-drive an external actuator (e.g., a robotic device).

Topics:

- Introduction of current BCI systems based on Electroencephalography (EEG).
  General concepts of BCI: structure, modules and applications for control and rehabilitation. BCI based on evoked potentials. BCI based on sensorymotor rhythms. BCI based on voluntary attention focus.
- Application of signal processing techniques to analyze EEG signals.
  Stationarity and non-stationarity of brain signals. EEG bands. Spatial and spectral filters.
- Application of machine Learning algorithms to classify EEG signals
  Machine learning approaches to BCI. Classical classifiers exploited in BCI field (e.g., LDA, QDA, Gaussian). Concepts of calibration and testing sessions. Stability of the classifier over sessions.
- Application of probabilistic frameworks to decode intention to move
  Decision making algorithms. Applications of bayesian probabilistic framework to decode sensorymotor rhythms.

- High-level BCI control of robotic actuators
  From the BCI output to the device control. Dealing with a noisy control signal. Common approaches to drive complex robotic devices.
- Implementation of an online BCI system from the beginning
  A real BCI experiment: subject setup, recording, calibration and testing. Experiment will be performed during the class. Critical points in the implementation of a working BCI loop. The recorded data will be used by students for the final project.

References:

[1] D. J. McFarland and J. R. Wolpaw, Brain-Computer interface operation of robotic and prosthetic devices, Computer (Long. Beach. Calif)., vol. 41, no. 10, pp. 5256, 2008.

[2] J. R. Wolpaw, Brain-computer interfaces for communication and control, Clin. Neurophysiol., vol. 113, no. 6, pp. 76791, 2002.

[3] N. Birbaumer, Breaking the silence: Brain-computer interfaces (BCI) for communication and motor control., Psychophysiology, vol. 43, no. 6, pp. 51732, 2006.

[4] J. d. R. Millán, et al., Combining brain-computer interfaces and assistive technologies: State-of-the-art and challenges., Front. Neurosci., vol. 4, no. September, pp. 115, 2010.

[5] G. R. Müller-Putz, et al., Tools for Brain-computer interaction: A general concept for a hybrid BCI., Front. Neuroinform., vol. 5, no. November, p. 30, 2011.

[6] C. M. Michel, et al., eds. Electrical Neuroimaging. 1st ed. Cambridge: Cambridge University Press, 2009.

[7] C. M. Bishop, Neural Networks for Pattern Recognition. Oxford University Press, Inc., New York, NY, USA, 1995.

Additional selected reference material will be handed out during the course.

Time table: Course of 22 hours. Class meets every Tuesday 16:30 to 18:30 and Thursday from 14:30 to 16:30. First lecture on Thursday, November 5th, 2016. Room DEI/G (3-rd floor, Dept. of Information Engineering, via Gradenigo Building).

Course requirements: Basic knowledge of signal processing. Basic knowledge of machine learning. Basic knowledge of Matlab and C/C++.

Examination and grading: Homework assignments and final project.

17 Statistical Methods

Instructor: Prof. Lorenzo Finesso, Istituto di Elettronica e di Ingegneria dell'Informazione e delle Telecomunicazioni, IEIIT-CNR, Padova, e-mail: `lorenzo.finesso@unipd.it`

Aim: The course will present a small selection of linear 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 of a probability measure and I-divergence (a.k.a. relative entropy, Kullback-Leibler distance) between two probability measures.

Divergence minimization problems. Three 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.

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. Derivation of Burg spectral estimation method as solution of a Maximum Entropy problem. Introduction to HMM

(Hidden Markov Models). Maximum likelihood estimation for HMM via the EM method.

References: A set of lecture notes and a list of references will be posted on the web site of the course.

Time table: Course of 24 hours (two lectures of two hours each per week). Class meets every Monday and Wednesday from 14:30 to 16:30, starting on Monday, April 18-th, 2016. Meeting Room DEI/G (3-rd floor, Dept. of Information Engineering, via Gradenigo Building).

Course requirements: Basics of probability, basics of linear algebra.

Examination and grading: homework assignments and take-home exam.

18 Random Graphs and Stochastic Geometry in Networks

Instructor: Professor Subhrakanti Dey, Signals and Systems, Uppsala University, Sweden
e-mail: `Subhra.Dey@signal.uu.se`

Aim: Complex networks are everywhere in real life. The most well known complex networks that we use everyday is the Internet and different forms of wireless networks. These are classical examples of Information Networks. Then there are various other types of networks such as biological networks in the human and animal bodies, social networks, citation networks, and many more. Modelling and analyzing such large-scale complex networks is a daunting task. Fortunately, mathematical tools such as *Random Graphs* and *Stochastic Geometry* allow us to construct simple but useful models of such networks, leading to tractable analysis and results that are surprisingly accurate for real world networks. Although these topics were historically developed from mathematical perspectives and used mostly in statistical physics, recent proliferation of large scale information and social networks has triggered a renewed research interest in using such tools for analyzing various forms of networks and developing design principles and resource allocation methods in complex new generation mobile communication networks for example. The applications of these tools are not just limited to a particular field, but have wide ranging applications in many areas including information network design and analysis, studying epidemic propagation, understanding social and biological networks etc. This course will deliver an introduction to the basic concepts and tools of random graphs and stochastic geometry. In addition, specific applications in wireless communication networks and the Internet, and multi-agent control networks in cyber-physical systems will be discussed.

Topics:

- *Lecture 1: Introduction to Random Graphs for Networks*: Introduction to different types of Networks, the role of random graphs in studying networks, some Probability Theory preliminaries, basic models of random graphs such as the *Erdős-Rényi random graph* or *Poisson random* *graph* and the $G(n, p)$ random graph, properties of random graphs such as mean number of edges and mean degree, degree distribution, clustering coefficient

- *Lecture 2: Random graphs and their properties*: Components of a random graph such as the *Giant Component* and *Small Components*, phase transitions in a random graph and threshold functions: appearance of a subgraph, appearance of the giant component and appearance of a connected graph

- *Lecture 3: Random graphs and their properties (continued)*: Sizes of the *small components* and their average behaviour,the complete distribution of the component sizes, path length behaviour in random graphs, the "small world effect", shortcomings of Random graph models in applications to real world networks

- *Lecture 4: Generalized Random Graphs*: Random graphs with general degree distributions, power-law distributions, size distributions of small components, giant component, other random graph models such as the random regular graphs

- *Lecture 5: Small world graphs and other random graph models*: The Small World model: a model that has high clustering coefficient and short average path length, degree distribution of the small world graph, clustering coefficient and the average path length of the small world graph, a short introduction to Exponential Random Graphs

- *Lecture 6: Basic Percolation Theory*: Introduction to lattice bond percolation theory: motivation and examples, formation of infinite-sized components in a percolated lattice and phase transition behaviour, phase transition in the random grid model: discrete percolation, percolation in interference limited networks

  Lecture 7: Consensus and Gossip algorithms: Introduction to consensus: linear consensus for distributed averaging, basic introduction to Graph theory and Laplacians, Perron-Frobenius theory for nonnegative matrices, consensus over random switching graphs, convergence results of linear consensus algorithms, gossip, randomized gossip and broadcast gossip algorithms and convergence

- *Lecture 8: Consensus and Gossip Algorithms*: Consensus over Markovian switching graphs, consensus for distributed estimation (filtering - linear and non-linear), consensus over wireless networks with various networking constraints and their effects on convergence
- *Lecture 9: Stochastic Geometry and its applications to wireless networks*: Introduction to Stochastic Geometry, Basic Point Process theory and properties, Point process transformations, Distributional Characterizations, General Point Processes, Cox Processes, Hard-core and Gibbs Processes
- *Lecture 10: Stochastic Geometry and its applications to wireless networks*: Sums and products of Point Processes, Moment Generating functional of sums over Poisson processes, Laplace functional and the probability generating functional for Point processes, Interference and outage probability characterization in Poisson Networks

References:

[1] Mark Newman, *Networks: An Introduction*, First Edition, Oxford University Press, UK, 2010.

[2] Bella Bollobas, *Random Graphs*, Second Edition, Cambridge Studies in Advanced Mathematics, Cambridge University Press, UK, 2001.

[3] M. Haenggi, *Stochastic Geometry for Wireless Networks*, Cambridge University Press, New York, 2013.

[4] M. Grossglauser and P. Thiran, "Networks out of Control: Models and Methods for Random networks", Lecture notes, EPFL, 2012.

[5] M. Franceschetti and R. Meester, *Random Networks for Communication: From Statistical Physics to Information Systems*, Cambridge University Press, UK, 2007.

Time table: Course of 20 hours. Class meets every Monday and Wednesday from 10:30 to 12:30. First lecture on Wednesday, March 30th, 2016. Room DEI/G (3-rd floor, Dept. of Information Engi- neering, via Gradenigo Building)

Course requirements: Advanced calculus, and probability theory and random processes.

Examination and grading: A project assignment for students in groups of 2 requiring about 20 hours of work.

19 Resonant converters and inverters: topologies and modeling

Instructor: Prof. Giorgio Spiazzi, e-mail: `spiazzi@dei.unipd.it`

Aim: the increased demand for more efficient and compact power supplies for a variety of applications together with the availability of faster switching devices, has pushed the switching frequency of modern power supply from tens of kilohertz toward the megaherz range. At such frequency values, the corresponding switching losses become unacceptable and soft-commutations become mandatory. In this contest, resonant converter and inverter topologies have been rediscovered as valid alternative to classical PWM topologies. The aim of this course is to provide basic knowledge of resonant converter topologies, their operation as well as their modeling and control, together with suggestions on the best design procedures for different applications.

Topics:

1. Switching losses in Pulse Width Modulated converters.
2. Basic dc-dc resonant converter topologies.
    - state-plane analysis;
    - fundamental component analysis.
3. LLC resonant converter.
4. Bidirectional resonant converters (Dual Active Bridge).
5. LCC resonant inverter for fluorescent lamps.
6. Modeling of resonant converters and inverters.

References:

[1] lecture notes and written material on specific topics

Time table: Course of 20 hours. Class meets every Tuesday and Thursday from 10:30 to 12:30. First lecture on Tuesday, May 24, 2016. Meeting room DEI/G, 3rd floor, Dept. of Information Engineering (via Gradenigo building).

Course requirements: basic knowledge of Power Electronics.

Examination and grading: homework and final examination.

20 Applied Machine Learning in Biomedicine

Instructor: Prof. Enrico Grisan, e-mail: `enrico.grisan@dei.unipd.it`

Aim: The course will introduce advanced topics in machine learning and pattern recognition and how they apply to real world problems. In this course we will present the mathematical background of some classification/regression tools, and show the pros and cons of their application to biomedical problems with extensive case studies.

Topics:

- Introduction to classical machine learning problems.
- Linear models for classification.
- Neural Networks
- Kernel methods and Support Vector Machine
- Ensamble methods
- Sparse coding (if time allows)

References:

[1] Christopher M. Bishop, Pattern Recognition and Machine Learning (Information Science and Statistics), Springer 2007

[2] Kevin P. Murphy, Machine Learning - A probabilistic Perspective, MIT Press 2012

Time table: Course of 16 hours. Class meets every Tuesday and Thursday from 14:30 to 16:30. First lecture on Tuesday, May 24, 2016. Meeting room DEI/G, 3^{rd} floor, Dept. of Information Engineering (via Gradenigo building).

Course requirements: Basics of probability theory. Basics of Matlab programming. The course "Bayesian Machine Learning" is suggested.

Examination and grading: Homework assignments and final project.

21 Quantum Statistical Dynamics and Control, F.Ticozzi

Instructor: Prof. Francesco Ticozzi , e-mail: `ticozzi@dei.unipd.it`

Aim: The course starts by providing an introduction to (elementary) quantum mechanics from the viewpoint of probability theory, accessible without any quantum mechanics background. The second part of the course is devoted to the definition and the study of quantum dynamical semigroups. This class of dynamics is widely used to model physical systems of interest in quantum information and control. In the last part of the course, some applications, illustrating the use of the mathematical tools developed, will be presented, including problems of information encoding and state preparation for finite-dimensional systems.

Topics:

- **Quantum Theory as a Probability Theory:** Densities, observable quantities, measurements in a non-commutative setting. Composite systems and entanglement. Partial trace and marginal densities. (4h)
- **Quantum Dynamical Systems:** Unitary dynamics, open quantum systems and quantum operations. Kraus representation theorem. Examples for two-level systems. Quantum dynamical semigroup and completely positive generators, and their representations. (4h)
- **Stability Analysis:** Basic stability properties, existence and structure of the invariant sets. Elements of Lyapunov-type analysis and natural Lyapunov functions. (4h)
- **Applications:** Noiseless encodings of quantum information; Preparation of states, subspaces and subsystems; Feedback master equations and their control. (4h)

References:

- Lecture notes and supplementary material provided by the instructor;
- A good introductory reference to modern quantum mechanics for finite-dimensional systems is contained in the first chapters of:

M. A. Nielsen and I. L. Chuang, Quantum Computation and Quantum information (Cambridge, 2000).

- A "classic" reference for continuous-time dynamical semigroups is: R. Alicki and K. Lendi, Quantum Dynamical Semigroups and Applications. Springer-Verlag, Berlin, 1987.

Time table: Course of 16 hours. Class meets every Monday and Wednesday from 10:30 to 12:30. First lecture on Wednesday, June 1st, 2016. Room DEI/G, 3-rd floor, Dept. of Information Engineering, via Gradenigo Building.

Course requirements: Linear algebra and probability theory.

Examination and grading: Homeworks.