TECHNICAL UNIVERSITY OF CRETE

School of Electrical & Computer Engineering

Graduate Studies Program
2021 - 2022

Chania 2021

1. Introduction

The School of ECE offers high–level engineering education with emphasis in four different areas: Computer Science, Electronics and Computer Architecture, Systems, and Telecommunications. These correspond to the four administrative divisions of the School and represent respective research areas.

The program of graduate studies, which was initiated in 1993, has a research focus; it currently offers M.Sc. and Ph.D. degrees in Electrical and Computer Engineering. **A total of 356 M.Sc. and 52 Ph.D. students have graduated from the School of ECE so far.** Both degrees require (a) the registration, attendance, and successful examination in graduate courses offered by the school; (b) the completion of a research M.Sc. thesis or an original Ph.D. dissertation under the supervision of a faculty member of the School. The Ph.D. dissertation must represent original research, published in peer–reviewed international journals and conferences.

Most of the faculty members have earned their Ph.D. degrees from top universities around the world and many have pursued careers as tenure track or tenured faculty members abroad before joining the School of ECE. The current high level of scientific activity, peer–reviewed publications, and competitive research funding of the School of ECE are due to the unrelenting efforts and talent of the graduate students and their close collaboration with the faculty of the School, as well as their active involvement in research projects run by the School. The international recognition of ECE is evidenced in the numerous publications in top scientific journals and international conferences, several best paper awards earned from the Institute of Electrical and Electronic Engineers (IEEE) by ECE faculty and student publications (both in journal publications and at international conferences), participation of the faculty in top journal editorial boards and top international conference program committees, etc. The School has demonstrated continuous improvement in academic quality which is due to the continuous efforts of the faculty, staff, and students.

Many students who have graduated with an M.Sc. or Ph.D. degree from the School of ECE currently hold tenured or tenure–track faculty positions at top US and European institutions, research positions at university research labs, national research and industrial development labs, and have founded and run technology spin-offs or work as professional engineers in Greece, Europe, and the USA.

The present Graduate Program Guide provides information about the program of graduate studies in the School of ECE. Further information can be found on the website of School of ECE (www.ece.tuc.gr).

2. Scope and Goals of the Program

The strategic goal of ECE's graduate program is to enable, sustain, and constantly improve the research conducted by the members of the School, as well as to improve the research and innovation ecosystem of the School and the Technical University of Crete.

Specialization is sought in the following areas:

A. Electronics & Computer Architecture
B. Telecommunications
C. Systems
D. Informatics
E. Applications of Information Society
F. Data analysis including big data
G. Energy
H. Physics
I. Mathematics

The School of ECE actively pursues new and emerging areas of research including the development of novel methodologies for the analysis, storage, and modeling of big data as well as applications of machine and statistical learning methods in practical problems of current interest. In particular, such problems may be motivated by the European priority research areas (Horizon Europe Global Challenges and European Industrial Competitiveness) which include health, culture, creativity and inclusive society, civil security for society, digital economy, industry and space, climate, energy and mobility, food, bioeconomy, and natural resources, agriculture, and environment.

3. Faculty

Dimitris G. Angelakis, Associate Professor
B.Sc. & M.Sc. University of Crete, Greece, 1998.
Ph.D. Imperial College, London, UK, 2002.

Costas Balas, Professor
B.Sc. University of Patras, Greece, 1988.
Ph.D. University of Patras, Greece, 1992.

Nikolaos Bekiaris-Liberis, Assistant Professor
Diploma National Technical University of Athens, Greece, 2007.
M.Sc. University of California, San Diego, USA, 2010.
Ph.D. University of California, San Diego, USA, 2013.

Aggelos Bletsas, Professor
Diploma, Aristotle University of Thessaloniki, Greece, 1998.
M.Sc. MIT, USA, 2001.
Ph.D. MIT, USA, 2005.

Matthias Bucher, Associate Professor
Diploma Swiss Federal Institute of Technology–Lausanne, Switzerland, 1993.
Ph.D. Swiss Federal Institute of Technology–Lausanne, Switzerland, 1999.

Georgios Chalkiadakis, Associate Professor
B.Sc. University of Crete, Greece, 1997.
M.Sc. University of Crete, Greece, 1999.
Ph.D. University of Toronto, Canada, 2007.

Stavros Christodoulakis, Professor Emeritus
B.Sc. National and Kapodistrian University of Athens, Greece, 1971.
M.Sc. Queen's University, Kingston, Canada, 1977.
Ph.D. University of Toronto, Canada, 1981.

Antonis Deligiannakis, Professor
Diploma National Technical University of Athens, Greece, 1999.
M.Sc. University of Maryland, USA, 2001.
Ph.D. University of Maryland, USA, 2005.

Vassilis Digalakis, Professor
Diploma National Technical University of Athens, Greece, 1986.
M.Sc. Northeastern University, USA, 1988.
Ph.D. Boston University, USA, 1992.

Apostolos Dollas, Professor
B.Sc. University of Illinois at Urbana–Champaign, USA, 1982.
M.Sc. University of Illinois at Urbana–Champaign, USA, 1984.
Ph.D. University of Illinois at Urbana–Champaign, USA, 1987.

Demosthenes Ellinas, Professor
B.Sc. University of Patras, Greece, 1980.
Ph.D. University of Helsinki, Finland, 1990.

Minos Garofalakis, Professor
Diploma University of Patras, Greece, 1992.
M.Sc. University of Wisconsin-Madison, USA, 1994.
Ph.D. University of Wisconsin-Madison, USA, 1998.

Dionissios Hristopulos, Professor
Diploma National Technical University of Athens, Greece, 1985.
Ph.D. Princeton University, USA, 1991.

Sotiris Ioannidis, Associate Professor
B.Sc. University of Crete, Greece, 1994.
M.Sc. University of Crete, Greece, 1996.
M.Sc. University of Rochester, USA, 1998.
Ph.D. University of Pennsylvania, USA, 2005.

Fotios Kanellos, Associate Professor
Diploma National Technical University of Athens, Greece, 1998.
Ph.D. National Technical University of Athens, Greece, 2003.

George Karystinos, Professor
Diploma University of Patras, Greece, 1997.
Ph.D. State University of New York at Buffalo, USA, 2003.

Eftichios Koutroulis, Associate Professor
Diploma Technical University of Crete, 1996.
M.Sc. Technical University of Crete, 1999.
Ph.D. Technical University of Crete, 2002.

Michail Lagoudakis, Associate Professor
Diploma University of Patras, Greece, 1995.
M.Sc. University of Louisiana–Lafayette, USA, 1998.
Ph.D. Duke University, USA, 2003.

Athanasios Liavas, Professor
Diploma University of Patras, Greece, 1989.
Ph.D. University of Patras, Greece, 1993.

Katerina Mania, Professor
B.Sc. University of Crete, Greece, 1994.
M.Sc. University of Bristol, UK, 1996.
Ph.D. University of Bristol, UK, 2001.

Daphne Manoussaki, Assistant Professor
B.Sc. University of Oxford, UK, 1991.
Ph.D. University of Washington, Seattle, USA, 1996.

Michael Paterakis, Professor
Diploma National Technical University of Athens, Greece, 1984.
M.Sc. University of Connecticut, USA, 1986.
Ph.D. University of Virginia, USA, 1988.

Euripides Petrakis, Professor
B.Sc. National and Kapodistrian University of Athens, Greece, 1984.
Ph.D. University of Crete, Greece, 1993.

Minos Petrakis, Associate Professor
B.Sc. National and Kapodistrian University of Athens, 1980.
M.Sc. University of Illinois at Urbana-Champaign, 1982.
Ph.D. University of Illinois at Urbana-Champaign, 1987.

Vassilis Samoladas, Associate Professor
Diploma Aristotle University of Thessaloniki, Greece, 1992.
M.Sc. University of Texas at Austin, USA, 1995.
Ph.D. University of Texas at Austin, USA, 2001.

George Stavrakakis, Professor
Diploma National Technical University of Athens, Greece, 1980.
M.Sc. Institut National des Sciences Appliquées, Toulouse, France, 1981.
Ph.D. Université Paul Sabatier [Toulouse III], France, 1984.

Michael Zervakis, Professor
Diploma Aristotle University of Thessaloniki, Greece, 1983.
M.Sc. University of Toronto, Canada, 1985.
Ph.D. University of Toronto, Canada, 1990.

4. Degree Requirements

4.1 Master of Science (M.Sc.)

Three specializations are available, leading to a Master of Science (M.Sc.) in Electrical and Computer Engineering:

Specialization A: Telecommunications, Signal Processing and Automatic Control.

Specialization B: Computer Science and Engineering.

Specialization C: Electronics, Energy and Quantum Systems.

The program has a minimum duration of three academic semesters (90 ECTS) and the M.Sc. students are offered two study options:

Option 1: three 7-ECTS courses plus 69-ECTS thesis.

Option 2: seven 7-ECTS courses plus 41-ECTS thesis.

Coursework is considered completed if the student achieves a grade at least six (out of ten) in each course and the average grade over all courses is at least seven and a half.

For both study options, the M.Sc. students are expected to publish (or report mature research results that can be published) in first class conferences and/or journals. Additional credits from the undergraduate program of School of ECE may be requested for specific M.Sc. applicants who have not received a 5-year undergraduate diploma in Electrical & Computer Engineering (ECE).

Before graduation, the M.Sc. thesis supervisor is expected to submit a brief report, summarizing the thesis contributions.

Public defense of the thesis is mandatory.

The duration of study can be extended up to five academic semesters for full-time graduate students.

The M.Sc. program complies with the provisions of the Greek national law. Applicants who have obtained their Bachelor or Master's degrees from non-Greek Universities need to have their degrees approved by the National Academic Recognition Center (NARIC) in order to fulfill the graduation requirements from the program.

4.2 Doctor of Philosophy (Ph.D.)

The course load for Ph.D. applicants consists of at least three full-credit courses. Applicants who do not possess M.Sc. or integrated Master's degrees are required to take at least six full-credit courses. The coursework requires the approval of the academic advisor and should comply with ECE guidelines. Additional credits from the undergraduate program of School of ECE may be requested for Ph.D. applicants who have not received a 5-year undergraduate diploma in Electrical & Computer Engineering (ECE). The Ph.D. program complies with the provisions of the Greek national law. Applicants who have obtained their Bachelor or Master's degrees from non-Greek Universities need to have their degrees approved by the National Academic Recognition Center (NARIC) in order to fulfill the graduation requirements of the PhD program.

Ph.D. applicants must also present two lectures which will be open to the entire community. Their progress is closely monitored by a three-member committee, including the advisor.

Before graduation, the Ph.D. thesis supervisor is expected to provide a brief report, summarizing the novel contributions of the thesis.

Public defense of the thesis is mandatory.

The maximum duration of the studies is twelve semesters for applicants without an M.Sc. or eight semesters for applicants with an M.Sc. from the ECE School (or other equivalent M.Sc. program).

Further details can be found at the School's website.

5. Admission Procedure

Admission opens three times per year, before the beginning of each academic semester and once in mid-summer. The call for applications and the respective deadline are announced at the School's website.

Applicants must provide three recommendation letters and must have secured a thesis supervisor who must be a faculty member of the School.

Recommendation letters must be uploaded by the application deadline on the online application system. Applicants are advised to make necessary arrangements with supporting recommenders well before the deadlines.

Conditional admission to the graduate program can be granted to students who have not completed all undergraduate program graduation requirements but are close to graduation.

Specifically for Ph.D. applicants, an M.Sc. in a field relevant to Electrical & Computer Engineering is necessary. Such requirement can be waived only for special cases of strong academic merit, according to the provisions of Greek national law.

Further details can be found at the School's website and in the respective call for applications.

6. Courses per Specialization

6.1 Graduate Courses

Course	Spec. A	Spec. B	Spec. C
Advanced Computer Architecture		*	*
Pattern Recognition	*	*	
Advanced Image Processing	*		*
Advanced Topics in Convex Optimization	*		
Advanced Topics in Time Series Analysis with R	*	*	*
Big Data Processing and Analysis	*	*	
Coding Theory	*		
Decision Making and Learning in Multi-Agent Worlds		*	
Detection & Estimation	*	*	
Information Management Methods		*	
Introduction to Probabilistic Graphical Models (PGM) & Inference Algorithms	*	*	
Machine Learning	*	*	
Nonlinear Systems	*		
Physics, Technology and Applications of Electronic Imaging Sensors and Systems			*
Probabilistic Robotics		*	
Secure Systems	*	*	
Selected Topics in Databases		*	
Selected Topics for User Interface Interaction Design		*	
Selected Topics in Computer Graphics		*	
Selected Topics in CMOS Analog Circuit Design			*
Selected Topics in Electric Measurements Systems			*
Selected Topics in Electric Power Systems			*
Theory of Probability and Random Processes	*	*	
Selected Topics in Mathematical Biology	*		

Topics in Advanced Automatic Control	*		
Visualization and Virtual Reality		*	

6.2 Cross-listed Graduate Courses

Course	**Spec. A**	**Spec. B**	**Spec. C**
Analysis and Design (Synthesis) of Telecom Modules (cross-listed)	*		
CAD Tool Development for Integrated Circuit Design		*	*
Computational Geometry		*	
Convex Optimization	*	*	
Data Management and Processing in Sensor Networks		*	
Design of VLSI and ASIC Systems			*
Electronic Energy Management Systems			*
Elements of Mathematical Analysis	*	*	
Introduction to Quantum Information		*	*
Modeling and Performance Analysis of Communication Networks	*		
Number Theory and Cryptography	*	*	
Optoelectronics			*
Quantum Technology		*	*
Principles of Distributed Systems		*	
Randomized Algorithms	*	*	
Reconfigurable Computer Systems		*	
Stochastic Processes and Time Series Analysis	*	*	*

7. Brief Descriptions of All Graduate Courses

Advanced Computer Architecture (B, C)

Advanced topics in computer architecture: thorough study on architectures that highly exploit instruction level parallelism: super-scalar (with in-order and out-of-order instruction execution), VLIW and EPIC, multi-scalar, multi-threading and simultaneous multi-threading (SMT). Instruction and data flow prediction, analysis on processor partitioning for higher clock frequency and lower power consumption. Network interface integration for processors targeting parallel systems. Advanced topics on cache memories, trace-cache. High performance memory systems and buses, architectural techniques for reducing power consumption. Study and comparison on state-of-the-art high performance processors (case studies).

Advanced Concepts in Machine Learning and Pattern Recognition (A, B)

The course develops on the theoretical underpinnings of machine learning, addressing also issues of explainability in learning. The course provides a broad and detailed consideration of the issues in machine learning, datamining, and statistical pattern recognition. Topics include: Regression and Classification; Image Categorization vs Segmentation; Regularization to prevent overfitting the training data; Neural Networks: Representation & Learning; Associations of Neural with brain networks: Perception, abstraction and detailed recognition; Evaluation of Machine Learning; Machine Learning System Design; Addressing skewed data; Dimensionality Reduction; Anomaly Detection; Large Scale Machine Learning vs Transfer Learning.

Advanced Topics in Convex Optimization (A)

The course covers advanced topics in convex optimization and the material may change. Topics that are usually covered include: information complexity of black box models for (convex) optimization problems, subgradient method, optimal first – order methods for convex optimization, accelerated gradient, proximal operator and proximal method, Projections onto convex sets, (Block) Coordinate Descent method, Alternating Direction Method of Multipliers, Stochastic gradient.

Advanced Topics in Time Series Analysis with R (A, B, C)

Introduction to the R Programming Environment, Review of basic concepts in time series analysis, ARMA(p,q) Models, SARIMA models for time series with complex trends and periodicities, Nonlinear auto-regressive, conditionally heteroskedastic models (ARCH/GARCH), Parameter estimation (method Cochrane/Orcutt, methods of generalized least squares and maximum likelihood) , Optimal model selection and residual analysis, Cross validation methodologies, Forecasting methodologies (for stationary time series, time series with trends and periodicities, exponentially weighted smoothing), Analysis of multivariate time series, Estimation of cross-covariance function, Transfer function models, Pre-whitening transformations, Nonlinear time series analysis with dynamical systems theory.

Advanced Image Processing (A, C)
This course develops on advanced concepts and techniques for image processing, in association with computer vision. Provides major understand of mathematical and statistical approaches, Demonstrate computer vision and image processing system design and implementation in advanced applications and prepare for research in computer vision and image processing. Topics include: Image formation and perception, image representation, sparse image analysis; Image segmentation, geometric transforms and registration; Morphological image processing; Object recognition, template matching, classification; Object detection and tracking: background modeling, kernel-based tracking; Camera models, stereo vision.

Analysis and Design (Synthesis) of Telecom Modules (A; cross-listed)
Synthesis of fundamental theory for telecom engineers, complemented with experimental practice in real-world conditions. Fundamental elements of transceivers and system parameters. Receiver parameters: noise figure, compression point (IP2), intermodulation and third-order intercept point (IP3), spurious receiver response. Transmitter parameters: frequency stability and spurious signals, output power efficiency, intermodulation. Receiver architectures: heterodyne, homodyne and subsampling receivers. Software-defined radio receivers. Elements of electromagnetic wave theory, transmission lines and antennas. Synthesis of telecom modules: super-heterodyne receiver (system blocks and electronics). Laboratory exercises on ultra-low cost, embedded radio links and programming of software-defined, embedded networks. Printed circuit board (PCB) design and implementation. Term project.

Big Data Processing and Analysis (A,B)
Effective compression techniques for high-volume data sets: sampling, histograms, wavelets; Approximate query processing; Continuous data streams: basic models, problems, and applications; Algorithms and tools for data-stream processing: reservoir sampling, basic sketch structures (AMS, FM, etc.); Distributed data streaming: Models and techniques; Modern big data management systems.

CAD Tool Development for Integrated Circuit Design (B, C; cross-listed)
The purpose of this course is to understand what CAD tools are, including tradeoffs of how utilities such as sed/awk or perl vs. the use of Python lead to the development of efficient CAD tools. The range of CAD tools considered is in the full-stack design flow (but mostly the back-end). The methodologies and mathematics which are used to develop CAD tools, as well as problems which arise in the process are considered. Such problems may be the rate of convergence, the choice of the correct mathematical tools (e.g. Monte Carlo methods vs. graph-based methods for place and route), or the tradeoffs of CAD tool quality vs. computational requirements (e.g. why can't we use Spice for circuits with one billion transistors?). The course is breadth-oriented and as such it covers the entire range of CAD-tool development: circuit simulation (with analytical methods such as Newton-Raphson, simplified switch-level models, and macromodels), netlist extraction (and manipulation) from layout, placement, routing, power analysis, formal verification/model checking, testing/testability. The course does not cover at all graphical interfaces – only "command line" tools are considered,

as the focus of the course is on the tools themselves and not the user interface. The course has very extensive programming exercises (typically in C/C++) spanning the range of the material taught, plus a project to cover one aspect in more depth. The project may be a mini-SPICE simulator for up to 100 MOS transistors, or a Monte-Carlo-based place and route tool for standard cells.

Coding Theory (A)

Principles of information theory (entropy, mutual information, capacity). Algebraic structures (group, ring, field, polynomial, finite field, vector space). Channel coding (channel code, error correction, linear code, generator matrix, dual code, parity-check matrix, syndrome decoding). Cyclic codes (encoding, generator and parity-check polynomials, Hamming and Golay codes, error detection, CRC codes, byte-level encoding and decoding). Bose-Chaudhuri-Hocquenhem code. Reed-Solomon code (construction, encoding, decoding, syndromes, error-locator polynomial). Convolutional codes (encoding, Viterbi decoding, BCJR decoding). Turbo code (encoding, BCJR and log-BCJR decoding, stopping criterion). Polar code (basic and general channel transformations, encoding, successive cancellation decoding, list decoding, polar code design for BEC and BSC).

Computational Geometry (B; cross-listed)

A theoretical class which combines topics from standard and discrete geometry with an overview of the major methods in algorithm analysis and design. Raster and vector data representation. The geometry of linear spaces. Abstract data types for geometric objects in 2 and 3 dimensions, precision issues, general position. Convex hull algorithms, intersection problems, planar subdivisions. Intersections for segments and curves. Polygon triangulations and visibility. Data structures: k-d tree, interval tree, segment tree, range trees, partition trees, external memory data structures. Point location via persistence, Mulmuley's tree and its analysis. Voronoi diagrams, Fortune's algorithm. Delaunay triangulation, duality with the Voronoi diagram, algorithms. Geometry in high dimensional spaces, curse of dimensionality. Metric spaces, norms and similarity. Nearest neighbor. Approximate methods, quad-trees, canvas methods, locality sensitive hashing. Linear programming and applications.

Convex Optimization (A, B; cross-listed)

Functions of several variables, partial derivatives, gradient, Hessian, lines, planes. Convex sets (definition, properties, examples). Convex functions (definitions, properties examples). Convex optimization problems: local and global optima, characterization of optimal solutions for differentiable functions. Problems of unconstrained convex optimization: optimal solutions, descent methods, gradient descent, line-search, backtracking, convergence analysis of the gradient descent method for strongly convex and smooth functions, Newton method (algorithm and local convergence analysis). Constrained optimization, Farkas's Lemma, Fritz John conditions, constraint qualification, Karush-Kuhn-Tucker (KKT) optimality conditions, duality, Lagrangian, Lagrange Dual function, weak/strong duality, interpretation of

Lagrange multipliers. Convex optimization with affine equality constraints: KKT conditions, quadratic problem with affine equality constraints, Newton method, primal-dual algorithm. Convex optimization with affine equality and convex inequality constraints, KKT conditions, logarithmic barrier functions, interior point methods. Implementation of simple gradient algorithms on distributed systems using Message Passing Interface (MPI).

Data Management and Processing in Sensor Networks (B; cross-listed)
Sensor nodes: Characteristics, constraints. Sensor network applications. Distributed data processing in sensor networks. Continuous Queries. Types of continuous queries and their characteristics. Query Languages. Data collection techniques (pull–based and push–based). Data storage, indexing and search techniques. Aggregation tree. Synchronization and data transmission. Different techniques of forming the aggregation tree. Distributed sensor (self)–organization. Approximate queries in sensor networks. Observing moving objects. Information loss and duplicate calculation of information: means of handling such issues. Quality of sensor measurements. Ways of isolating and removing spurious measurements. Secure Aggregate Queries in Sensor Networks.

Decision Making and Learning in Multi-Agent Worlds (B)
Utility Theory, Decision Theory, Game Theory (cooperative/non-cooperative). Rationality and strategic decision making. Reinforcement Learning and Multiagent Reinforcement Learning. Elements of Unsupervised Learning and Probabilistic Topic Modeling. Deep Learning and Deep Reinforcement Learning. Learning in game-theoretic and multiagent environments.

Design of VLSI and ASIC Systems (C; cross-listed)
Very Large-Scale Integration (VLSI) circuit technology, Field Effect Transistor (FET) principles, CMOS technology. Processing technologies, design flows and design rules. Ratioed logic. Complementary CMOS logic circuits, pass–transistor logic, transmission gates. Digital circuit design methodologies for special applications (ASIC) and digital system design issues. Dynamic logic. Precharging techniques. Sequential circuits, two-phase and multi-phase clocks. Datapath design. Static and dynamic RAM design. Power and clock distribution. Testing of VLSI systems. Economic analysis of VLSI systems.

Detection & Estimation (A, B)
Revision of Linear Algebra and Probability. Binary Hypothesis Testing Examples; Sufficient Statistics, Receiver Operating Characteristic (ROC) & Neyman-Pearson Tests. Gaussian Detection. M-ary Hypothesis Testing and Performance Analysis Bounds. Bayesian Estimation, Properties of Mean Squared Error and Linear Least Squares Estimators. Estimation of Non-random parameters, Cramer-Rao Bound (theorem, proof, examples). Uniform Minimum Variance Unbiased (UMVU) Estimators, RBLS Theorem. Asymptotic Behavior of Maximum Likelihood (ML) Estimators, BLUE Estimators. Composite Hypothesis Testing: UMP Tests, GLR Tests (GLRT) and

Asymptotic Properties of GLRT. Standard Kalman/Wiener Filtering. Iterative parameter estimation: Expectation-Maximization (EM). Introduction to non-parametric estimation: particle filtering.

Electronic Energy Management Systems (C; cross-listed)
Design of DC-DC and DC-AC power converters. Battery structures for electric energy storage. Electronic systems for maximizing power production (Maximum Power Point Tracking – MPPT). Smart meters. Special sensors, actuators and controllers for energy management and energy saving in Smart Homes/Buildings. Electronic energy management systems for Renewable Energy Sources, Smart Grids, Microgrids and electric vehicles. Electronic systems for wireless power transmission and energy harvesting.

Elements of Mathematical Analysis (A, B; cross-listed)
Metric Spaces, compactness, completeness, Baire's Theorem, Lebesgue Integral, measurable Sets, Linear Operators on normed spaces, the three basic principles of Functional Analysis, Krein-Milman's Theorem.

Information Management Methods (B)
Processing, archiving, and searching of information including documents, one–dimensional signals, still and moving images (video) in information systems and the Internet. Classic models of information retrieval (binary, relational, probabilistic), information clustering and clustering algorithms (partitional, hierarchical, hybrid algorithms), clustering applications grouping in document collections. Visualization of one–dimensional signals and images in multimedia systems. Feature extraction (color, texture, shape, and spatial relationships) from images. Retrieval methods for one–dimensional signals and images. Indexing techniques in information systems for documents and multimedia information (inverted files, k–d trees, grid files, R–trees, space filling curves). Design of information systems on the Internet, management and analysis of information on the Internet (PageRank and HITS methods). Web crawling and focused crawling. Iintroduction to Semantic Web. Ontology basics, ontology tools, and their application to information systems. Basic processing techniques and analysis of still and moving images (video) in information systems. Compression techniques, JPEG, MPEG–1, 2, 4, 7 standards. Video segmentation into shots, shot aggregates.

Introduction to Probabilistic Graphical Models (PGM) & Inference Algorithms (A, B)
PGMs encode (conditional) dependencies among random variables on carefully crafted graphs. Such description is powerful enough to describe a variety of many famous algorithms, such as (Gaussian) Belief Propagation, Kalman Filtering, Viterbi, Expectation-Maximization. This class offers an introduction in representation with PGMs, algorithms for exact inference, approximate inference, and learning/estimation: Directed acyclic graphs (DAGs) (Bayesian Nets) factorization theorem and semantics (I-map, d-separation, p-map). Undirected graphs (Markov Blanket, Hammersley-Clifford theorem), factor graphs (and techniques to convert), Gaussian Graphical Models. Exact Inference (elimination algorithm, sum-

product/belief propagation, max-product on Trees, HMMs and Kalman Filtering, Junction Tree algorithm). Approximate Inference: Loopy Belief Propagation, Sampling Methods (Particle Filtering, Metropolis-Hastings). Intro to learning graphs: ML Techniques, Chow-Liu, BIC-based Techniques, Expectation-Maximization. Term projects will thoroughly study application examples in diverse domains.

Introduction to Quantum Information (B, C; cross-listed)
State vector Hilbert spaces - Qubit - Theory of quantum measurements, orthonormal complete bases, projectors, positive operator valued probability measures POVM. Unitary time evolution. Density matrix, properties, spectral decomposition, convex decomposition. Bloch sphere and vector. Introduction to quantum entanglement. Quantum correlations – Bipartite systems - Biorthogonal analysis - Schmidt numbers. Measures of entanglement - Quantum entropy measures. Quantum information. The Schroedinger-HJW theorem. Uhlmann-Nielsen theorem -Majorization. Quantum channels (Single qubit - collective channels). Quantum algorithms - Complexity issues. Computational and communicational algorithms. The Deutsch-Jozsa algorithm. Quantum teleportation algorithm for states, gates, channels. The LOCC protocol. Grover's quantum search algorithm. Quadratic speed ups. Quantum walks (QW). Coin-walker Hilbert spaces. QWs on lines, circles, planes. The QW channel map. Fast diffusion.

Machine Learning (A, B)
Basic concepts of machine learning and statistics. Supervised learning: least mean squares (LMS), logistic regression, perceptron, Gaussian discriminant analysis, naive Bayes, support vector machines, model selection and feature selection, ensemble methods (bagging, boosting). Learning theory: bias/variance tradeoff, union and Chernoff/Hoeffding bounds, VC dimension. Unsupervised learning: clustering, k–means, EM, mixture of Gaussians, factor analysis, principal components analysis (PCA), independent components analysis (ICA). Reinforcement learning: Markov decision processes (MDPs), Bellman equations, value iteration, policy iteration, value function and policy approximation, least–squares methods, reinforcement learning algorithms, partially observable MDPs (POMDPs), algorithms for POMDPs.

Modeling and Performance Analysis of Communication Networks (A; cross-listed)
Introduction to the Stochastic Modeling of Communication Networks. Quick Review of Basic Probability and Stochastic Processes Concepts: Random Variables, Expected Values and Conditional Expectations, the Bernoulli Stochastic Process and Sums of Independent Random Variables, the Poisson Stochastic Process and its Main Properties. Discrete Time Markov Chains (Properties, Classification of States, Limiting Behavior and Applications). Introduction to Modeling of Communication Networks via Queueing Theory: Little's Theorem, Markovian Queues (M / M / 1, M / M/ m, M / M / m / m), the Queue with Generalized Distribution of Service Times (M / G / 1), the M / G / 1 Queue with Server Vacations, Markovian Queues with Customer Arrivals of Different Priorities, Reversible Markov Chains – Burke's theorem, Open Queueing Networks – Jackson's Theorem. Applications in the Design, Modeling and Performance

Analysis of Communication Network Protocols: Media Access in Packet Transmission Networks (Protocols: ALOHA, Tree Packet Collision Resolution, Transmission Time Scheduling based on Channel Reservations), Media Access and Transmission Scheduling in Wireless Integrated Services Networks.

Nonlinear Systems (A)

Phase portrait. Second-order systems. Existence and uniqueness of solutions. Sensitivity equations. Comparison principle. Lyapunov stability. LaSalle theorem. Linearization. Center manifold theorem. Stability of perturbed systems. Input-to-state stability. Input-output stability. Perturbation theory and averaging. Singular perturbations. Circle and Popov criteria. Nonlinear control design using backstepping.

Number Theory and Cryptography (A, B)

Divisibility theory, congruence, the Chinese Remainder Theorem. Fermat's Theorem, Euler's Theorem. Order and primitive roots. Discrete logarithms. Single- and multiple-key cryptosystems. RSA, knapsack, and ElGamal cryptosystems. Authentication. Groups, rings, integral domains, fields. Polynomial arithmetic. Galois fields, construction and properties. DES and AES cryptosystems.

Optoelectronics (C; cross-listed)

Atoms, Molecules, Photons, Radiation and Matter Interaction Phenomena, Laser Physics and Technology, Electronic Imaging Systems, Light Transmission Phenomena, Fiber Optics Physics and Technology, Polarization and Light Modulators, Optical Fiber-based Telecommunication Networks.

Physics, Technology and Applications of Electronic Imaging Sensors and Systems (C)

Photodetectors, photodiodes and phototransistors, photovoltaic, band gap and spectral response, responsivity, quantum efficiency, noise types, time response, photodiode circuits, medical uses in spectroscopy, dosimetry etc., CCD silicon imaging sensors, charge storage and transfer, charge to voltage conversion read our circuits, noise, full well capacity and dynamic range, CMOS silicon imaging sensors, correlated sampling, color imaging with silicon detector, infrared photon and thermal cameras, X-ray cameras, performance evaluation-Modulation Transfer Function (MTF) of imaging systems, digital X-ray imaging systems: technology and quality assessment, applications in hyperspectral imaging and noninvasive medical diagnosis.

Principles of Distributed Systems (B)

The class contains a brief overview of Distributed Systems technology: Models and mechanisms for Inter-Process Communication: sockets, shared memory, group communication, remote procedure calls, distributed objects. Introductory network programming. Sessions. Protocols. Distributed system architectures: client-server, multi-tier, mediators, code migration, distributed agents, peer-to-peer systems. Naming and addressing: names, physical and logical addresses, name services, DNS. Distributed catalogs, LDAP. Service-oriented architecture. An introduction to formal methods in concurrency. Reactive systems, properties, safety and liveness properties.

Dijkstra's guarded commands, the UNITY language and the UNITY logic. Proofs in shared-memory concurrent systems. Time in distributed systems. Causality. Lamport clocks and vector clocks. Global state and global predicates. Snapshots. Fundamental algorithms: mutual exclusion, leader election, termination detection, byzantine agreement. Observability and consistency. Distributed data structures, distributed hash tables, distributed garbage collection. Fault tolerance: backup systems, redundancy, two- and three-phase commit. Fault tolerant agreement: PAXOS and Raft. Security: authentication and authorization. Elements of cryptography, symmetric and asymmetric cryptography, certificates and PKI. Digital signatures, SSL and Kerberos. Zero-knowledge proofs, secure multiparty computation.

Probabilistic Robotics (B)

Uncertainty and probabilistic reasoning. Robotic perception and action. Recursive state estimation: state space, belief space, prediction and correction, Bayes filter. Estimation filters: linear Kalman filter, extended Kalman filter, unscented Kalman filter, histogram filter, particle filter. Probabilistic motion models: velocity model, odometry model, sampling and probability density. Probabilistic observation models: beam model, scan model, feature model, sampling and probability density. Robot localization: Markov, Gaussian, Grid, Monte-Carlo. Robotic mapping: occupancy grid maps, feature maps, simultaneous localization and mapping (SLAM). Decision making under uncertainty, Markov decision processes (MDPs), optimal policies, value iteration, policy iteration. Partial observability, partially-observable MPDs (POMDPs), augmented MDPs. Reinforcement learning, prediction and control, trial and error, approximate representations. Multi-robot planning, coordination, and learning.

Quantum Technology (B, C; cross-listed)

The Stern-Gerlach experiment and the necessary quantum approach. Basic concepts of quantum theory. Dirac notation, operator methods in quantum mechanics: linear operators and representations. The axioms of Quantum Mechanics: State space, time evolution and Schroedinger's equation, Quantum Measurement (projective measurement). Quantum bit and Bloch sphere. Single qubit gates. Two qubit states and EPR. Quantum transformations, Pauli matrices and two qubit gates. Quantum circuits and applications. The superdense coding and quantum teleportation protocols. Quantum computing and quantum parallelism. Deutsch and Deutsch-Jozsa algorithms. Grover's algorithm for searching in unstructured databases. Quantum programming and the IBM's Qiskit language and applications. Basics of state- -of-the-art quantum implementation technologies. The quantum supremacy demonstration by Google with 53 qubits: Basic concepts. The Di-Vincenzo criteria for quantum implementations. Quantum dipole dynamics in E/M field and application in implementing quantum gates: Precession motion, Rabi oscillations, single qubit gates, implementation of NOT and Hadamard gates. Interaction Hamiltonians for two spin qubits: Ising and Heisenberg cases. Implementation of SWAP and CNOT gates in two qubits. Elements and state of the art in superconducting quantum hardware and cold ions. Basics of advanced quantum algorithms and quantum machine learning.

Randomized Algorithms (A, B; cross-listed)

Check of polynomial multiplication and matrix-vector multiplication via randomized algorithms. Randomized min-cut algorithm. Discrete random variables: Bernoulli, Binomial, Geometric. The coupon collector problem. Quick-sort: probabilistic analysis. Markov inequality, Chebyshev inequality. Randomized algorithm for the computation of the median. Chernoff inequality, Hoeffding inequality. The balls and bins problem, multinomial distribution. Random graph models, randomized algorithm for the computation of a Hamiltonian cycle in a graph. Probabilistic method (expectation method, second-moment method). Probabilistic algorithm for the computation of large cuts in graphs. Martingales: definition, examples, Hoeffding-Azuma inequality.

Reconfigurable Computer Systems (B; cross-listed)

Introduction, definitions, Reconfigurable logic as a means of computations. Historical examples (Splash 2, RaPiD, Piperench) and areas of applications (DNA sequencing, discrete mathematics problems, image processing, speech processing, etc.). Comparison of FPGA systems with other implementation technologies (DSP, VLSI, conventional computers CPU, and Graphics Processing Units-GPU). Evolution of CAD tools for synthesis and place and route of reconfigurable designs, high-level synthesis (HLS) tools. Evolution of FPGA architectures. Granularity of subsystems and large hardcore subsystems (Embedded processors, BRAM, CAM, PLL/DLL, etc.). Dynamic reconfiguration and partial reconfiguration–opportunities and limitations. Semester project.

Secure Systems (A, B)

The goal of the course is the introduction of students into state-of-the-art research topics in the area of network and systems security. Topics include: access control models and mechanisms, malware, phishing, botnets, spam, denial of service (DoS), code injection, race conditions, and defenses.

Selected Topics in CMOS Analog Circuit Design (C)

Introduction to the design of advanced analog integrated circuits (ICs). Introduction to nanometric CMOS technology. Evolution of CMOS technology and scaling according to Moore's law. Conventional bulk CMOS, SOI CMOS, FinFET and other multi-gate CMOS technologies. High-voltage and power MOSFETs. Advanced MOSFET compact models and process design kits (PDKs) for the design of integrated circuits. Characterization and modeling of MOSFETs from DC to high frequencies and noise. Principles of advanced analog/RF IC design. Design of high-frequency amplifiers and oscillators.

Selected Topics in Databases (B)

This course covers a selection of the following topics: Design and implementation issues in databases. Design and implementation of relational systems. Design and implementation of object–oriented systems. XML databases. Query optimization in databases. Optimizing the performance of applications with design at the physical level, cost optimization for transactions, recovery. Distributed databases. Data Warehousing. Data mining on databases. Continuous Databases. Stream Processing. Big Data Systems and Frameworks.

Selected Topics in Electric Measurements Systems (C)
Sensors–transducers–detectors (applications, characteristics, selection, classification). Structure of a measurement system, signal conditioning, linearization. Selected topics in measurement of temperature, position, displacement, level, speed, acceleration, force, torque, pressure, flow, current, light and sun irradiation. Optical detectors, advanced transducers, chemical and biochemical sensors. Selected topics in electromagnetic influence on sensors and measurement equipment. Analog signal processing, instrumentation amplifiers, isolation amplifiers, chopper amplifiers, programmable gain amplifiers. Selected topics in multiplexing and sampling, A/D and D/A converters, data-acquisition and processing systems and data-loggers. Sensor networks and communication protocols. Applications on automation and design examples. Reference voltage circuits. Smart sensors, wireless sensors. Measurement instruments.

Selected Topics in Electric Power Systems (C)
State of the Art and future prospects for Electric Power Systems. Technical challenges in generation, transmission and distribution of electric power, control and supervision systems. The main subjects examined in the course are the following: characteristics and technical challenges of distributed electric power generation, microgrids (island and grid-connected operation), smart demand response, smart grids and their applications (smart metering, distributed control techniques, load shifting), active distribution networks, energy management of large clusters of electric vehicles connected to the network, “smart" electric energy storage, virtual power plants, hybrid power plants, "smart" producers-consumers of electricity (prosumers), flexible electric power transmission systems, high voltage direct current interconnection systems.

Selected Topics in Mathematical Biology (A)
Mathematical models in biological systems. Stability analysis and bifurcation diagrams. Enzyme kinetics. Michaelis Menten theory. Introduction to perturbation methods. Autocatalysis, activation, inhibition. Feedback control mechanisms. Biological oscillators. Limit cycles. Introduction to partial differential equations. The diffusion equation. Reaction - diffusion - chemotaxis models. Travelling wave solutions. Reaction - diffusion (Turing) mechanisms. Pattern initiation in reaction-diffusion mechanisms. Various problems in ecology, biology and / or physiology will be presented.

Selected Topics for User Interface Interaction Design (B)
The aim of this course is to analyze use cases for user interface design principles, including interaction design rules, implementation of user interfaces, quantitative and qualitative evaluation metrics for user interface design. Selected use cases of psychophysical methodologies are going to be presented in relation to perceptual thresholds of user sensitivity regarding issues which negatively affect user interaction with technological systems.

Selected Topics in Computer Graphics (B)

Rendering equation optimized based on visual perception principles. Local and global illumination. Photorealistic algorithms optimized based on fidelity metrics. User interfaces and controllers for virtual reality. Advanced ergonomy for simulations. Advanced topics in ray tracing, animation, visualization. Selective rendering algorithms. Fidelity metrics based on visual perception principles. Fidelity metrics for simulations and simulation engineering.

Stochastic Processes and Time Series Analysis (A, B, C; cross-listed)

The concept of stochastic process (continuous-discrete time), Simple stochastic processes (sequences of independent random variables) , Expectation, autocorrelation and autocovariance functions, Non-negative definite functions, Impulse function (Dirac delta), White noise process, Stationarity in the strict and wide (weak) sense, Permissible autocovariance models, Frequency domain description, power spectral density, periodogram estimation, Gaussian stochastic processes, Wiener stochastic process, Fractional Brownian motion, Convergence in the mean square sense, Continuity and differentiability for stochastic processes, Poisson process, Basic concepts of time series, The trend-fluctuations-noise model, Bias and consistency of statistical estimators, Non-linear transformations for heteroscedastic time series, Estimation and elimination of trend and periodicity, Discrete-time models of stochastic processes: moving average (MA), autoregressive (AR), and autoregressive moving average (ARMA), Yule-Walker equations, Estimation of model parameters and linear prediction (basic principles).

Theory of Probability and Random Processes (A, B)

Probability spaces, Random Variables and Stochastic Processes, Conditional Probability, Expected Values, Conditional Expectations, Independence of Random Variables. The Bernoulli Stochastic Process and Sums of Independent Random Variables: Bernoulli Process, Number of Successes, Times of Successes, Sums of Independent Random Variables, Chebyshev Inequality, Weak and Strong Law of Large Numbers, Central Limit Theorem. The Poisson Stochastic Process: Stochastic Arrival Processes, Definition of the Poisson Arrival Process, Numbers of Arrivals, Times of Arrivals, Equivalent Definitions, Properties of the Poisson Arrival Process, Superposition of Independent Poisson Arrival Processes, Randomly Partitioning the Arrivals of a Poisson Process. Markov Chains: Introduction, Visits to a given State, Classification of States, Markov Chains of Birth and Death type, Markov Chains with Countably Infinite States. Limiting Behavior of Markov Chains, Recurrent States and Calculation of their Steady State Probabilities, Application of Markov Chain Limiting Behavior Results in Queueing Theory.

Topics in Advanced Automatic Control (A)

Optimization theory of static nonlinear functions of many variables with or without constraints. Introduction to calculus of variations for the minimization of functionals under various boundary conditions. Functional minimization theory for multivariate nonlinear dynamical systems. Kuhn–Tucker conditions of optimality extraction. Application in solving the generalized problem of the multivariable non-linear optimal control problem with constraints. Presentation of the Pontryagin's maximum principle and its application in the optimal control (extraction of the necessary optimality conditions) of multivariable non-linear and linear dynamic systems with non-linear or quadratic optimization criterion. Numerical methods for solving the Riccati matrix differential equation for the calculation of the optimal control of linear multivariate systems with a quadratic optimization criterion of continuous and discrete time. Identification (estimation) theory. Recurrent least squares method. Applications in the estimation of unknown parameters of dynamic multivariable continuous and discrete systems. Multivariable Kalman Filter. Stochastic optimal control. Technological and industrial applications of the above.

Visualization and Virtual Reality (B)

The aim of this course is the familiarization with visualization and virtual reality technologies as well as the development of virtual reality systems, employing industry-standard software tools for 3D modelling and APIs and software platforms for the implementation of 3D interactive applications. The course is evaluated based on the successful technological development of an interactive virtual reality and 3D interactive application, based on principles of human computer interaction.

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