**ENG EC 500 A1 Introduction to Online Learning**  
Prof Orabona

This course deals with the foundations and advances of online learning and online convex optimization. The main theme of the course is the design and theoretical understanding of algorithms that make sequential decisions in adversarial environments, striving to perform as close as possible to a fixed strategy that knows the future in advance. Special attention will be paid to parameter-free, efficient, and practical algorithms. The focus will be on theorems and proofs for the analysis of online learning algorithms. Time permitting, we will also try to cover applications of online learning to stochastic optimization, boosting, portfolio selection, and statistical machine learning topics. 4cr

**ENG EC500 A2 Robot Learning and Vision for Navigation**  
Prof Ohn-Bar

The class is designed to bring the basic concepts of software engineering together and practice them in real life examples. We will focus on studying different concepts that the students have taken in different classes or were not exposed to that are necessary for their careers in one place. Class focuses on developing product quality software. The class builds on EC601 and EC602. In the class, we will focus on software development principles and techniques including agile development, continuous integration, build and delivery. We will focus on modular design concepts, product quality (testing framework, unit testing), debugging, concurrency, data flow, and API design. 4cr

**ENG EC500 A3 Principles of Software**  
Prof Trachtenberg

Scaling software to many developers, modules, or machines requires a fundamentally different skillset from writing short prototype code. Software engineers working on large-scale web, financial and healthcare systems, or even multiplayer gaming must synthesize a wide variety elements at all abstraction layers, ranging from hardware and operating system constraints through considerations of distributed execution, security, databases, and front-end development.

This course will focus on the **principles** of scalable software engineering, including:

- **Design** – how to design code for efficiency, modularity, interoperability, security, and extensibility
- **Distribution** – the issues inherent in efficient and reliability distributed processing over many machines
- **Optimization** – the effects of design and distribution on performance, how optimization down to the hardware
- **Security** – fundamental elements of secure software design and implementation

The course will include significant amounts of programming, primarily in C++ and Java, but possibly in some higher-level languages as well. Students will be expected to learn language elements and software tools as needed, on the fly, and to collaborate in increasingly complex and collaborative programming projects. A fundamental background in software programming is thus mandatory, although a background in data structures or algorithms may also be helpful (but not required). 4cr

**ENG EC501 A1 Dynamic System Theory**  
Prof Baillieul

Introduction to analytical concepts and examples of dynamic systems and control. Mathematical description and state space formation of dynamic systems; modeling, controllability, and observability. Eigenvector and transform analysis of linear systems including canonical forms. Performance specifications. State feedback: pole placement and the linear quadratic regulator. Introduction to MIMO design and system identification using computer tools and laboratory experiments. Same as ENG ME 501 and ENG SE 501. Students may not receive credit for both. 4cr

**ENG EC 503 A1 Introduction to Learning from Data**  
Prof Ishwar

This is an introductory course in statistical learning covering the basic theory, algorithms, and applications. This course will focus on the following major classes of supervised and unsupervised learning problems: classification, regression, density estimation,
clustering, and dimensionality reduction. Generative and discriminative data models and associated learning algorithms of parametric and non-parametric varieties will be studied within both frequentist and Bayesian settings in a unified way. A variety of contemporary applications will be explored through homework assignments and a project. 4cr

**ENG EC 504 A1 Advanced Data Structures**  
Prof Brower

Review of basic data structures and Java syntax. Data abstraction and object-oriented design in the context of high-level languages and databases. Design implementation from the perspective of data structure efficiency and distributed control. Tailoring priority queues, balanced search trees, and graph algorithms to real-world problems, such as network routing, database management, and transaction processing. 4cr

**ENG EC 505 A1 Stochastic Processes**  
Prof Castanon


**ENG EC 516 A1 Digital Signal Processing**  
Prof Nawab

Advanced structures and techniques for digital signal processing and their properties in relation to application requirements such as real-time, low-bandwidth, and low-power operation. Optimal FIR filter design; time-dependent Fourier transform and filterbanks; Hilbert transform relations; cepstral analysis and deconvolution; parametric signal modeling; multidimensional signal processing; multirate signal processing. 4cr

**ENG EC 521 A1 Cybersecurity**  
Prof Stringhini

Fundamentals of security related to computers and computer networks. Laws and ethics. Social engineering and psychology-based attacks. Information gathering, network mapping, service enumeration, and vulnerability scanning. Operating system security related to access control, exploits, and disk forensics. Shellcoding. Wired and wireless network security at the physical, network, and application layers. Theoretical lessons are augmented with case studies and demonstrative experimental labs. 4cr

**ENG EC 524 A1 Optimization Theory and Methods**  
Prof Paschalidis

Introduction to optimization problems and algorithms emphasizing problem formulation, basic methodologies, and underlying mathematical structures. Classical optimization theory as well as recent advances in the field. Topics include modeling issues and formulations, simplex method, duality theory, sensitivity analysis, large-scale optimization, integer programming, interior-point methods, non-linear programming optimality conditions, gradient methods, and conjugate direction methods. Applications are considered; case studies included. Extensive paradigms from production planning and scheduling in manufacturing systems. Other illustrative applications include fleet management, air traffic flow management, optimal routing in communication networks, and optimal portfolio selection. Same as ENG EC 674, ENG SE 524, ENG SE 674. Students may not receive credit for both. 4cr

**ENG EC 525 A1 Optimizing Machine Learning**  
Prof Cutkosky

Efficient algorithms to train large models on large datasets have been critical to the recent successes in machine learning and deep learning. This course will introduce students to both the theoretical principles behind such algorithms as well as practical implementation considerations. Topics include convergence properties of first-order optimization techniques such as stochastic gradient descent, adaptive learning rate schemes, and momentum. Particular focus will be given to the stochastic optimization problems with non-convex loss surfaces typically present in modern deep learning problems. Additional topics may include second-order methods and variance reduction. After completing this course, students should be able to read, understand, and implement optimization algorithms from current research. 4cr

**ENG EC 528 A1 Cloud Computing**  
Prof Liu
Graduate Prerequisites: ENG EC 504; Graduate students must have taken a rigorous programming class recently, such as EC504 or equivalent (or have major software design experience in industry).

Fundamentals of cloud computing covering IaaS platforms, OpenStack, key Big Data platforms, and data center scale systems. Examines influential publications in cloud computing. Culminates in a group project supervised by a mentor from industry or academia. Same as CAS CS 528. Students may not receive credits for both. 4cr

**ENG EC 533 A1 Advanced Discrete Mathematics**  
Prof Levitin


**ENG EC 545 A1 Cyber-Physical Systems**  
Prof Li

This course introduces students to the principles underlying the design and analysis of cyber-physical systems - computational systems that interact with the physical world. We will study a wide range of applications of such systems ranging from robotics, through medical devices, to smart manufacturing plants. A strong emphasis will be put on building high-assurance systems with real-time and concurrent behaviors. The student will gain both in-depth knowledge and hands-on experience on the specification, modeling, design, and analysis of representative cyber-physical systems. Same as ENG SE 545. Students may not receive credits for both. 4cr

**ENG EC 551 A1 Advanced Digital Design with Verilog and FPGA**  
Prof Densmore

Content includes use of HDL (Verilog) for design, synthesis and simulation, and principles of register transfer level (RTL). Programmable logic, such as field programmable gate array (FPGA) devices, has become a major component of digital design. In this class the students learn how to write HDL models that can be automatically synthesized into integrated circuits such as FPGA. Laboratory and homework exercises include writing HDL models of combinational and sequential circuits, synthesizing models, performing simulation, and fitting to an FPGA by using automatic place and route. The course has lab orientation and is based on a sequence of Verilog design examples. 4cr

**ENG EC 555 A1 Introduction to Biomedical Optics**  
Prof Bigio

This course surveys the applications of optical science and engineering to a variety of biomedical problems, with emphasis on optical and photonics technologies that enable real, minimally-invasive clinical and laboratory applications. The course teaches only those aspects of the biology itself that are necessary to understand the purpose of the applications. The first weeks introduce the optical properties of tissue, and following lectures cover a range of topics in three general areas: 1) Optical spectroscopy applied to diagnosis of cancer and other tissue diseases; 2) Photon migration and diffuse optical imagine of subsurface structures in tissue; and 3) laser-tissue interactions and other applications of light for therapeutic purposes. Some classes will invoke traditional lectures, and others will be "inverted," devoted to discussing and understanding application problems, with students having read textbook sections or online material prior to class. Same as ENG BE 555. Students may not receive credit for both. 4cr

**ENG EC 562 A1 Engineering Optics**  
Prof Dal Negro

The goal of this course is to present a coherent formulation of wave propagation, radiation and diffraction phenomena in arbitrary linear systems for the engineering design of optical devices in strong partnership with computer simulations and engineering-led design projects. The course will introduce students to the fundamental techniques that are necessary for the quantitative analysis of optics-based engineering systems and devices. 4cr

**ENG EC 571 A1 Digital VLSI Circuit Design**  
Prof Yazicigil Ki
Very-large-scale integrated circuit design. Review of FET basics. Functional module design, including BiCMOS, combinational and sequential logic, programmable logic arrays, finite-state machines, ROM, and RAM. Fabrication techniques, layout strategies, scalable design rules, design-rule checking, and guidelines for testing and testability. Analysis of factors affecting speed of charge transfer, power requirements, control and minimization of parasitic effects, survey of VLSI applications. Extensive CAD laboratory accompanies course. 4cr

**ENG EC 573 A1 Solar Energy Systems** Prof Mazumder

This course is designed for first year graduate and senior undergraduate students from engineering disciplines. It is intended to educate students in the design and applications of solar energy technology. It will focus on fundamentals of solar energy conversion, solar cells, optical engineering, photoelectrochemical cells, thermoelectric generators, and energy storage and distribution systems. The course covers solar energy insolation and global energy needs, current trends in photovoltaic energy engineering, solar cell materials science, design and installation of solar panels for residential and industrial applications and connections to the national grid and cost analysis of the overall system. In addition, basic manufacturing processes for the production of solar panels, environmental impacts, and the related system engineering aspects will be included to provide a comprehensive state-of-the-art approach to solar energy utilization. Same as ENG MS 573. Students may not take credit for both. 4cr

**ENG EC 574 A1 Physics of Semiconductor Materials** Prof Bellotti

This course teaches the relevant notions of quantum mechanics and solid state physics necessary to understand the operation and the design of modern semiconductor devices. Specifically, this course focuses on the engineering aspects of solid state physics that are important to study the electrical and optical properties of semiconductor materials and devices. Particular emphasis is placed on the analysis of the electronic structure of semiconductor bulk systems and low-dimensional structures, the study of the carrier transport properties and the calculation of the optical response that are relevant to the design and optimization of electronics and photonics semiconductor devices. The students will learn to apply the quantum mechanical formalism to the solution of basic engineering device problems (quantum wells, wires, and dots, 2D electron gas) and to perform numerical calculation on more complex systems (band structure calculation of bulk and low dimensional systems). Same as ENG MS 574. Students may not receive credits for both. 4cr

**ENG EC 577 A1 Electronic Optical and Magnetic Properties of Materials** Prof Sharifzadeh

This course is intended to develop an in depth knowledge of solid state concepts that are important for students in the areas of material science and electrical engineering. Specifically, this course focuses on the study of different aspect of solid state physics necessary to study technologically relevant crystalline and amorphous systems. Particular emphasis is placed on the study of the crystal structure, crystal diffraction and the related techniques used as diagnostic tools; the electronic, thermal, optical and magnetic properties of material systems important for electronics and photonics device applications. Furthermore the course will also consider the theory of superconductivity, the chemistry aspects of solid state materials and will provide an introduction to solid state biophysics. This course complements EC 574 (Physics of semiconductor material) and EC 575 (semiconductor devices) with its focus on technologically relevant structural, optical, thermal and magnetic material properties. Same as ENG MS 577. Students may not receive credit for both. 4cr

**ENG EC 578 A1 Fabrication Technology for Integrated Circuits** Prof Kleptsyn

Presentation of fabrication procedures for silicon-integrated circuits: physical properties of bulk and epitaxially grown silicon; silicon processing, such as oxidation, diffusion, epitaxy, deposition, and ion implantation; silicon crystallography, anisotropic etching, photolithography, piezoresistivity, and chemical and plasma techniques. The limitations these processes impose on the design of bipolar and MOS devices and integrated circuits are discussed. Design of an integrated circuit and the required processing. Includes lab. 4cr

**ENG EC 579 A1 Nano/microelectronic Device Technology** Prof Cole
The main physical processes and manufacturing strategies for the fabrication and manufacture of micro and nanoelectronic devices will be covered, mostly for silicon, although exciting materials such as graphene and carbon nanotubes will also be covered. A key emphasis here will be on electron-hole transport, band structure, basic quantum effects, and the use of engineering and physical effects to alter semiconductor device performance. Photolithography, a significant factor in manufacturability, will be covered in some detail, and to a lesser degree, so will doping methods, diffusion, oxidation, etching, and deposition. The overall integration with methods and tools employed by device and circuit designers will be covered. Same as ENGME579. Students may not receive credit for both employed by device and circuit designers will be covered. Same as ENGME579. Students may not receive credit for both. 4cr

**ENG EC 591 A1 Photonics Lab 1**

Prof Paiella

Introduction to optical measurements. Laser safety issues. Laboratory experiments: introduction to lasers and optical alignment; interference; diffraction and Fourier optics; polarization components; fiber optics; optical communications; beam optics; longitudinal laser modes. Optical simulation software tools. 4cr

**ENG EC 601 A1 Product Design in Electrical and Computer Engineering**

Prof Alshaykh

Engineers influence their community, society and the world. Engineers build products and services that can enhance people's lives. The product starts with an idea and is delivered through research (technical and societal), design, implementation, testing and support. During this class, students will experience all of this. The course provides design and practical insights into building products that involve WEB and mobile app development, data simulation, analysis and modeling, cloud computing, signal processing and/or computer vision. In the class, we work on how to take an idea and concept and translate it into product requirements. Afterwards, we translate the product requirements into system and engineering requirements. We also discuss solution selection techniques. We then work on implementing our ideas into systems and verify that they address the product requirements and fulfill the concept we started with. During the class, we go over how to choose solutions to build our products. We also discuss real product realization, implementations and tradeoffs. The class is taught via an example product and the class sessions are interactive. Students are divided into groups where they work in parallel on their projects during class sessions and hackathons. Teams define their target audience, product mission, requirements and features. The class adopts agile software development based on a two-week sprint. Students present their sprint results to the class. 4cr

**ENG EC 602 A1 Design by Software**

Prof Carruthers

Software plays a central role in all aspects of electrical and computer engineering. This course will provide the foundation for effectively using software as a key part of a career as a professional electrical or computer engineer. Fundamentals of software development systems: system languages, high-level object-oriented languages, and computational languages. Data structures and algorithms in problem analysis and design. Strategies for designing software and designing with software. Software design and development: methodologies, principles and practice. Formalizing software: management, requirements, specifications, testing. Survey of software applications in ECE, including real-time systems, the web, networked systems, audio, graphics, and video systems, research and engineering analysis, consumer electronics and computing, instrumentation and measurement, design, modeling, prototyping, simulation, optimization and information analysis. Students can choose projects and assignments with application to/inspired by/drawn from a broad array of ECE fields including the traditional areas of electro-physics/photonics, computer engineering, and information and data science. Open to graduate students only. 4cr

**ENG EC 605 A1 Computer Engineering Fundamentals**

Prof Moreshet

This is an introductory course to computer engineering, focusing on the hardware/software interface, and presenting a bottom-up view of a computer system. Topics include logic design: binary arithmetic, combinational and sequential logic. Computer organization: assembly language programming, CPU design, and memory systems. Introduction to compilers, operating systems, and computer networks. Open to graduate students only. 4cr
This course is an introduction to optimization problems and algorithms emphasizing problem formulation, basic methodologies and the underlying mathematical structures. We will cover the classical theory as well as the state of the art. The major topics we will cover are: 1. Theory and algorithms for linear programming. 2. Introduction to combinatorial problems and methods for handling intractable problems. 3. Introduction to nonlinear programming. 4. Introduction to network optimization. Optimization techniques have many applications in science and engineering. To name a few: * Optimal routing in communication networks. * Transmission scheduling and resource allocation in sensor networks. * Production planning and scheduling in manufacturing systems. * Fleet management. * Air traffic flow management by airlines. * Optimal resource allocation in manufacturing and communication systems. * Optimal portfolio selection. * Analysis and optimization of fluxes in metabolic networks. * Protein docking. Prerequisites: Working knowledge of Linear Algebra and some degree of mathematical maturity. Same as ENG EC 674, ENG SE 524, ENG EC 674. Students may not receive credits for both. 4cr

**ENG EC 717 A1 Image Reconstruction and Restoration**

Principles and methods of reconstructing images and estimating multidimensional fields from indirect and noisy data; general deterministic (variational) and stochastic (Bayesian) techniques of regularizing ill-posed inverse problems; relationship of problem structure (data and models) to computational efficiency; impact of typically large image processing problems on viability of solution methods; problems in imaging and computational vision including tomography and surface reconstruction. Computer assignments. 4cr

**ENG EC 762 A1 Quantum Optics**