ELECTRICAL AND COMPUTER ENGINEERING

Departmental Facilities

The Department of Electrical and Computer Engineering is housed in Walter Light Hall which provides over 5,400 square meters of modern research, teaching and classroom facilities. The building is linked to Goodwin Hall which houses the School of Computing. Additional space for undergraduate laboratories and research is located in Beamish-Munro Hall.

Graduate research is supported by an extensive network of personal computers and workstations. In total, there are over one hundred workstations and personal computers maintained within the Department. The administration of the network is both open and flexible to allow the sharing of data, application software, and peripherals among all groups. In addition, an ATM fiber network is available for research use and several research groups also operate stand-alone computer systems linked to specialized research equipment. The Department also provides several computing laboratories to support both graduate and undergraduate courses. Installed operating systems include Unix, Windows, and Windows NT and a wide range of application software is available on both the teaching and research networks. Access to University wide computing resources, such as the Library systems and the Internet, is provided through high speed network switches.

Facilities in the Department include laboratories, with extensive modern equipment and instrumentation, dedicated to research in digital communications, cellular and satellite communications, wireless network and modems, computer communications, computer architecture and parallel processing, photonic packet switching network, information networks technology and network performance testing and monitoring, image processing, communication signal processing, array signal processing, video image compression, fiber optics, microwave integrated circuits, microwave communications, wireless communications, power electronics, electric drive systems, biomedical engineering, robotics and control systems.

A large number of graduate students are associated with projects being carried out under several federal and provincial centres of excellence, including Communications and Information Technology Ontario (CITO), Photonic Research Ontario (PRO), the Canadian Institute for Photonic Innovations (CIPI), and the Canadian Institute for Telecommunications Research (CITR). Graduate students whose research involves VLSI design have access to the facilities of the Canadian Microelectronics Corporation (CMC) which is located on the Queen's University campus.

Financial Assistance

Graduate students are frequently supported by one or more of external scholarships (such as Ontario Graduate Scholarships and Natural Sciences and Engineering Research Council Postgraduate Scholarships), University awards, research assistantships available from individual members of staff, and teaching assistantships. Teaching assistantships involve approximately 84 hours of work during the academic year and are offered, based upon Departmental needs, to full-time students in the first two years of the M.A.Sc. program and the first four years of the Ph.D. program. Student income typically ranges from $18,000 to $28,000 per annum, depending primarily upon whether or not an external scholarship is held. For further information, please contact the Coordinator of Graduate Studies in the department.

Areas of Research

The research activities of the Department fall into five broad areas:

- **Biomedical and Intelligent Systems** – Coordinator: M. Korenberg
  For detailed description see https://www.ece.queensu.ca/research/groups/biomedical-and-intelligent-systems.html
- **Communications and Signals Processing** – Coordinator: S. Blostein
  For detailed description see https://www.ece.queensu.ca/research/groups/comm-and-signals.html
- **Computer and Software Engineering** – Coordinator: N. Manjikian
  For detailed description see https://www.ece.queensu.ca/research/groups/computer-and-software-engineering.html
- **Microelectronics, Electromagnetics and Photonics** – Coordinator: J.C. Cartledge
  For detailed description see https://www.ece.queensu.ca/research/groups/mep.html
- **Power Electronics** – Coordinator: P. Jain
  For detailed description see https://www.ece.queensu.ca/research/groups/power-electronics.html

Applicants are accepted under the general regulations of the School of Graduate Studies.

Faculty

Head
Saavedra, C.

Chair of Graduate Studies

Liu, Y.-F.

Professor
Afsahi, A., Blostein, S.D., Bakhshai, A., Chan, W.Y.G., Dean, T.R., Frank, B., Freundorfer, A.P., Gazor, S., Greenspan, M., Hashtrudi-Zaad, K., Jain, P., Kim, I.-M., Korenberg, M.J., Liu, Y.-F., Morin, E.L., Rudie, K., Saavedra, C., Yam. S.,Yousefi, S., Zou, Y.

Associate Professor
Manijikian, N.

Assistant Professor
Alam, M., Ameri, S.K., Eren, S., Etemad, A.

Professor Emeritus
Cartledge, J.C., Eastham, A.R., Sen, P.C.

Cross-Appointed
Alajaji, F., Antar, Y.M.M., Fichtinger, G., Hassanein, H.S., Marshall, J., Mousavi, P., Noureldin, A., Troje, N., Zulkernine, M.

Adjunct Faculty
Pan, S.

Programs of Study

Master's Degrees

Master of Applied Science (M.A.Sc.)

This is a thesis/research based Master's program. The minimum requirement are a research thesis, a seminar course, and 4 term-length graduate-level courses, of which two courses must be selected from graduate courses offered by the Department of Electrical and Computer Engineering. One term length senior (400-series) undergraduate course, OR one combined undergraduate/graduate course (also known as a double numbered 400/800 course) may be accepted as the equivalent of a graduate course from any discipline for an M.A.Sc. student provided that

a) the course is approved by the student's supervisor and
b) the student has not received credit for a similar course in their Bachelor's program.

All students must attend department seminars to complete ELEC 891, the mandatory seminar series course. The requirements are set at the Department's discretion according to the student's background.

The supervisor(s) and department must approve all programs of study.

Master of Applied Science (M.A.Sc.) with a Field of Study in Artificial Intelligence

This is a thesis/research based Master's program with a Field of Study in Artificial Intelligence. The minimum requirements of the Field of Study in Artificial Intelligence are:

- Take a minimum of two courses from the list of AI-related courses, including ELEC 825
- Take up to two more graduate-only courses as required in the MASc program
- Complete an AI-related MASc thesis
- Complete other requirements including taking the graduate seminar course and the non-credit AI Ethics and Society course

List of AI-related courses:

- ELEC 823 Signal Processing
- ELEC 825 Machine Learning and Deep Learning
- ELEC 874 Computer Vision
- ELEC 879 Wearable and IoT Computing
- ELEC 880 Machine Learning for Natural Language Processing

The student must attend departmental seminars to complete ELEC 891, the mandatory seminar series course. The requirements are set at the Department's discretion according to the student's background.

The supervisor(s) and department must approve all programs of study.

Master of Engineering (M.Eng.) (Non-Thesis Option)

The requirements for this program are 8 term length courses. At least 4 term length courses must be taken from the Department of Electrical and Computer Engineering and be entered as primary on the registration form. A maximum of 2 term length 400 series undergraduate courses or double number 400/800 level courses or a combination thereof may be taken provided that:

a) the courses are approved by the student's supervisor or graduate coordinator and
b) the student has not received credit for similar courses in their Bachelor's program.

When:

a) 2 term-length 400 series undergraduate courses,
b) one 400 series undergraduate and one double number 400/800 graduate level courses, or
c) two double number 400/800 graduate level courses are taken,

the remaining courses must be graduate level courses and must not be combined undergraduate/graduate courses (also known as a double numbered 400/800 graduate level courses).

All the course selections must be approved by the Department.

These courses must be selected as follows:

1. Four term-length graduate courses must be courses offered in the Department.
2. Two of the courses in (1) may be replaced by ELEC 898-M.Eng. Project.
3. Normally, the remaining courses may be chosen from courses listed by the Department, or from courses offered by another department in Queen's University, or from Royal Military College.
4. The student must select at least one course that contains a project if not selecting the project course ELEC 898. A list of courses containing a project is maintained by the department.

Students must also take the non-credit seminar course ELEC 891.

Master of Engineering (M.Eng.) with Industrial Internship field

The M.Eng. with Industrial Internship field in Electrical and Computer Engineering requires students to take six term-length lecture-based courses, up to two of which can be fourth-year undergraduate courses. In addition, internship students take two term-length internship project courses (ELEC 895 and ELEC 896), for a total of eight courses. Students must also take the non-credit seminar course ELEC 891.

Further, the courses must be selected as follows:

1. ELEC 895 and ELEC 896;
2. At least two term-length graduate courses must be courses offered in the Department;
3. Normally, the remaining lecture-based courses may be chosen from courses listed by the Department, or from courses offered by another department in Queen's University, or from the Royal Military College.

If a student decides not to take ELEC 896, then they must take a total of seven term length lecture-based courses. This situation could arise for example if the duration of the internship job was only 4 months.

Doctor of Philosophy (Ph.D.)

During the first term, the Department in consultation with the student's supervisor(s) establish an Internal Thesis Committee consisting of the supervisor(s), an internal examiner, as well as a department representative. At this time, an area of research is chosen. The internal examiner should have expertise close to the candidate's general research area. The requirements to be fulfilled include a minimum of 4 term-length graduate courses beyond the Master's degree, a two-part comprehensive examination, the seminar course ELEC 891, satisfactory research progress and a thesis.

One of the graduate courses must be taken from outside the Department. One of the graduate courses must be taken inside the Department. Only 1 course may be a combined undergraduate/graduate course (also known as a double numbered 400/800 course).

For students who received a Master's from this department and in the same area of study, the minimum course requirements shall be decided in consultation with the PhD Advisory Committee and approved by the Department Head or Graduate Coordinator.

The supervisor(s) and the Department must approve all programs of study.

All Ph.D. candidates will take a comprehensive examination administered in two parts by the candidate's thesis committee. Part I deals with the candidate's background in his/her chosen area of research. Part II consists of the candidate's thesis proposal. The Ph.D. Part I report must be submitted to the Department within 10 months of the start of the program, and the Ph.D. Part I Comprehensive Examination should be held no later than two months from the report submission date. An external/internal examiner (outside ECE Department, within Queen's University) is added to the Internal Thesis Committee to form the Ph.D. Supervisory Committee for Part II. The Ph.D. Part II report must be submitted to the Department within 22 months of the start of the program, and the Ph.D. Part II Comprehensive Examination should be held no later than two months from the report submission date. After the successful completion of Part II, thesis research progress is reported by the candidate and reviewed by the Ph.D. Supervisory Committee annually.

Courses

All courses except ELEC 898 , ELEC 899 and ELEC 999 are 3.0 credit units. Not all courses are offered every year.

APSC 801 Master of Engineering Foundations
An introduction to the Master of Engineering (MEng) graduate studies program at Queen's University. The course provides students with essential administrative information, an introduction to information literacy within the Faculty of Engineering and Applied Science, as well as an overview of

the various support services on campus. Additionally, the course contains several modules on professional and career skills. This non-credit course is comprised of a number of individual modules, and its completion may be a requirement to graduate from the MEng program. Graded on a Pass/Fail basis.
Prerequisite: Enrolment in the MEng program.
Exclusion: Students not enrolled in the MEng program.

APSC 810 Teaching and Learning in Engineering
This course is an introduction to learning principles and effective teaching in engineering, intended to prepare for roles like teaching assistant, university course instruction, or training in engineering industry. The course includes relevant theories of teaching and learning with practical elements like classroom management, designing sessions and assessments, signature engineering teaching approaches, and using digital pedagogies. In Electrical and Computer Engineering, this course can be taken as a secondary (additional) course, or as an audited course, but will not count towards the coursework requirement of any graduate degree.

APSC 812 AI Ethics and Society
This course investigates the ethical implications of Artificial Intelligence (AI) as a social, technological and cultural phenomenon. Given the increasing use of intelligent systems for decision-making and autonomous control, it is essential that designers and developers are aware of the ethical and social implications that AI can have. The course materials will examine fundamental ethical principles related to the application of AI and investigate its influence in a number of industries including self-driving vehicles, healthcare, law and defense. The course will also examine the delicate balance between innovations in AI versus regulation, privacy, and individual rights. This course is graded on a Pass/Fail basis. This is a required course for Master of Applied Science students in the field of study in Artificial Intelligence in the Department of Electrical and Computer Engineering. Students in other graduate programs in the Department of Electrical and Computer Engineering must consult with the Department to confirm if this course will count towards the coursework requirement of their graduate degree.

APSC 877 Engineering Project Management
The course will examine the essential skills and knowledge required for effective engineering project management. The foundational principles of project management including integration, scope, cost, time, human resources, stakeholders and procurement are examined. The course will be delivered online. In Electrical and Computer Engineering, this course can be taken as a secondary (additional) course, or as an audited course, but will not count towards the coursework requirement of any graduate degree.
Exclusions: MECH 896, APSC 223

APSC 888 Engineering Innovation and Entrepreneurship
This course will help learners from across engineering develop an entrepreneurial mindset capable of turning problems into opportunities. Learners will investigate the relationships between innovation and industrial dynamics, and seek to understand the fundamental forces that drive the science and technology industries' evolution and industry life cycles. In Electrical and Computer Engineering, this course can be taken as a secondary (additional) course, or as an audited course, but will not count towards the coursework requirement of any graduate degree.
Exclusions: CHEE 410

APSC 896 Engineering Leadership
The course is designed to develop a range of leadership skills essential for engineering professional practice. Students will explore their own leadership abilities and develop their competencies in areas such as managing conflict, team dynamics and developing others. The course content will be presented through lectures, case studies, panel discussions and other active learning activities. In Electrical and Computer Engineering, students in the M.Eng. program can take APSC-896 as a primary course toward their program requirements. For students in the M.A.Sc. or Ph.D. program in Electrical and Computer Engineering, APSC 896 can be taken as a secondary (additional) course, but the course will not count towards the coursework requirement of the M.A.Sc. or Ph.D.

ELEC 823 Signal Processing
This course covers basic topics in statistical signal processing and machine learning with applications in speech, communication, and biomedical signal processing. The student is assumed to be familiar with digital signal processing rudiments such as discrete Fourier transforms and design and analysis of digital filters. Topics covered include: spectral modeling, linear prediction, optimal filtering, adaptive filters, Bayesian inference, linear models, support vector machines, neural networks, and hidden Markov models.

ELEC 825 Machine Learning and deep learning
Basic machine learning concepts in supervised and unsupervised learning; discriminative and generative models; backpropagation, FFN, CNN, RNN, autoencoders; regularization technologies; attention-based models, Transformer, Capsule Networks; pretraining and selfsupervised models; Generative Adversarial Networks (GANs), variational autoencoders; applications. Three term hours. Lectures. X. Zhu
PREREQUISITE: ELEC 326 or equivalent, or permission of the instructor.

ELEC 827 Multimedia Signal Processing
Study of multimedia signal processing for network mediated human-human communication and human machine interaction (HMI). Topics covered include: overview of multimedia applications and processing functions; speech production; human auditory and speech perception; image formation; human visual perception; perceptual quality and user experience modeling; speech and image analysis and synthesis methods; lossless and lossy compression techniques; coding for communication and storage; sensing modalities for HMI; machine learning algorithms for information extraction and understanding.Three-term-hours; lectures. Permission of instructor. G. Chan.

ELEC 830 Emerging Technologies in power grid
Renewable energy generation; wind and Photovoltaic energy conversion; energy storage; distributed energy generation; hybrid systems; Power electronics interfaces and control. Grid- connected distributed sources. Stand-alone operation of distributed sources and micro-grid systems. System protection. Economical dispatch. Centralized and decentralized control. Smart grid.

ELEC 831 Power Electronics
Fundamentals of loss-less switching techniques: zero-voltage switching, zero-current switching. Resonant converters: series, parallel and series-parallel topologies; Soft-switching converters: natural and auxiliary commutation converter topologies; Control techniques: variable frequency, phase-shift and hybrid control. Applications to single-phase three-phase and multi-level converters. Special emphasis will be placed on the design techniques using practical examples. PREREQUISITE: ELEC 431 or permission of instructor.

ELEC 832 Modeling and Control of Switching Power Converters
This course covers the modeling and control techniques for switching power converters. Small signal models and large signal models will be presented. Peak current mode control and average current mode control for switching power converters will be investigated. System stability issues when several power supplies are connected together are investigated and solutions are presented and analyzed. Digital control techniques, using FPGA or DSP, will be investigated and analyzed. Conventional fuzzy logic control and improved version of fuzzy logic control will be analyzed in detail. Sliding mode control and sliding mode like control will be analyzed. Digital control techniques for AC-DC converter with power factor correction will be analyzed. It is expected the students will do a project based one or more of the above mentioned techniques. Three term-hours, lectures, fall. Y.F. Liu.

ELEC 834 Micro-Grid Technology
This course covers various power electronics technologies for micro-grids, nano-grids and energy harvesting systems. In this course various types of micro-grids will be covered (e.g., AC microgrids, hybrid micro-grids, and DC micro-grids), along with their respective architectures and control systems. PREREQUISITES: ELEC 431 and ELEC 443, or equivalent, or permission of the instructor.

ELEC 835 Nonlinear Control for Power Electronics
This course provides an overview of advanced nonlinear control and its application in power electronics. It covers mathematical background and major topics in this area. Students will be introduced to the rigorous mathematical background for nonlinear systems particularly differential geometry. Then, the design of nonlinear control systems will be covered for power electronics applications. PREREQUISITES: ELEC 431 (Power Electronics) or equivalent or permission of the instructor, and ELEC 443 (Linear Control Systems) or equivalent.

ELEC 837 High Power Electronics
Introduction. Power semiconductor devices. Line- and force-commutated converters. High power ac/dc and dc/ac converter structures and switching techniques. Principles of HVDC and HVAC systems. Large and small scale stabilities, sub-synchronous resonances, inter-area oscillations, voltage sags, and harmonic instability. Voltage, power angle, and impedance control, phase balancing, and power factor correction by means of solid-state power converters. Flexible AC Transmission Systems (FACTS). Three term hours; lectures, Winter. A. Bakhshai

ELEC 841 Nonlinear Systems: Analysis and Identification
Analytical methods for nonlinear systems; nonlinear difference equation models: functional expansions and Volterra, Wiener and Fourier-Hermite kernels; kernel estimation techniques; identification of cascades of linear and static nonlinear systems; use of Volterra series to find region of stability of nonlinear differential equations; applications to pattern recognition, communications, physiological systems, and non-destructive testing. Three term-hours; lectures, Fall. M.J. Korenberg

ELEC 843 Control of Discrete-Event Systems
Study of discrete-event processes that require control to induce desirable behaviour. Topics include: basic automata and language theory; modeling of processes using automata (finite-state machines, directed graphs); centralized and decentralized problems; nonblocking supervisors; partial observation; and computational complexity. Connections with manufacturing systems and communication protocols are emphasized. Three term-hours; lectures, Fall. K. Rudie

ELEC 845 Vehicle Control and Navigation
The objective of this course is to introduce graduate-level engineering students to the fundamentals of autonomous vehicles engineering. The course focuses on those tasks usually carried out by autonomy engineers, including sensor selection, applied control (e.g., trajectory and path following) and navigation techniques for autonomous vehicles that operate in real environments (e.g., mining, construction, warehouses, roadways, etc.). Although the focus in this course is on ground vehicles, the presented methods are also applicable more broadly. The audience is engineers from all relevant engineering and applied science disciplines who have an interest in mobile robotics, applied control and estimation, and robotic vehicle applications. Three term hours, Lectures. J. Marshall
PREREQUISITES: ELEC 443, MECH-350 or equivalent undergraduate level course in control systems.
EXCLUSION: MINE-855

ELEC 848 Control Systems Design for Robots and Telerobots
This course provides an overview of manipulator modeling, and presents and analyzes many different control architectures designed for robots and telerobots. Topics include introduction to robotics and telerobotics; serial manipulator forward and inverse kinematics, Jacobian, singularities and dynamics; robot position and force control methodologies and their stability analyses; bilateral teleoperation control architectures, stability and performance issues due to communication delays and environment uncertainties. Three term hours, Lectures, Winter. Dr. K Hashtrudi-Zaad

ELEC 852 Broadband Integrated Circuits
Topics covered include broadband and ultra-wide band circuit design techniques with applications to wireless and lightwave systems. Broadband amplifiers, mixers and active filters are discussed using radio frequency, microwave and millimeter-wave methods. Three term hours; lectures.

ELEC 853 Silicon RF and Microwave Circuits
This course presents an introduction to the design of RF and microwave circuits using silicon technologies. Topics include: an overview of silicon technologies; the design of passive structures including transmission lines, inductors, and couplers; considerations in the layout of active devices; examples of the design of circuit components on silicon; system design including integrated system-on-chip designs; and a look at the future of silicon high-speed circuits. Three term-hours, lectures; Winter. B. Frank
PREREQUISITE: ELEC 483 or equivalent

ELEC 854 Microwave Circuits and Systems
Investigation of the design and performance of wireless circuits and systems at microwave and millimeter-wave frequencies. Topics include: communications transceivers, millimeter-wave imaging systems, RFID, radar systems, transmission lines and passive circuits, resonators, microstrip and lumped element low-pass and bandpass filters, amplifier noise and linearity, diode and transistor mixers, LC and relaxation oscillators, frequency multipliers and dividers, phase shifters, FSK QPSK and GMSK modulators and demodulators. Three term hours; lectures. C. Saavedra.

ELEC 855 Nanoelectronics and Nano-Devices
This course teaches the fundamentals of electron devices in nanometer regime. The course will cover introduction to the nanoelectronics, basics of quantum mechanics and band theory of solids. The concept of Coulomb blockade, many electrons phenomenon, ballistic and spin transport will be discussed and single electron transistor, quantum dots, nanowire and quantum wells based devices will be taught.
PREREQUISITES: ELEC 252, ENPH 336 or equivalent courses.

ELEC 856 Introduction to Nanophotonics
The course will provide an overview of the principles of operation of current nanophotonic devices, and recent advances in nanophotonics. Topics covered will include: light- matter interaction, optical waveguides, modeling of nanophotonic devices, light propagation in periodic and anisotropic media, coupled mode devices, plasmonics, metamaterial and metasurface. Emphasis of the course will be on the underlying physics behind the operation and design of nanophotonic devices.
PREREQUISITES: ELEC 381 or PHYS 239 or their equivalents.

ELEC 857 Selected Topics in RF Engineering
This course will cover advanced techniques in high-frequency electronics. Possible topics include ultra-low power circuits, wireless sensors, integrated antennas, microwave photonic circuits, RF technology for high-performance instrumentation.
PREREQUISITES: ELEC 353 and ELEC 381 (or their equivalents).

ELEC 859 Unconventional Computing
This course gives an overview of computing hardware from classic conventions to emerging frontiers: machine learning accelerators, quantum circuits, and others. It covers unconventional information representations, architectures, and programming. Assignments measuring cloud-based CPU, GPU, FPGA, neuromorphic, and quantum computers will give hands- on exposure to the physicality – the time, energy, and matter – of information processing. (3.0 credit units)

ELEC 860 Communication Network Analysis
This course provides an analytical study of communication networks that covers many of the major advances made in

this area. Students will be introduced to the mathematical preliminaries in queueing theory, optimization and control, followed by a rigorous treatment of network architectures, protocols and algorithms, including resource allocation, congestion control, routing, and scheduling that are essential to existing and future communication networks and the Internet. Three term-hours; lectures. N. Lu
PREREQUISITE: ELEC 326 (Probability and Random Processes) or equivalent.

ELEC 861 Probability, Random Variables and Stochastic Processes
The review of probability theory including probability spaces, random variables, probability distribution and density functions, characteristic functions, convergence of random sequences, and laws of large numbers. Fundamental concepts of random processes including stationarity, ergodicity, autocorrelation function and power spectral density, and transmission of random processes through linear systems. Special random processes, including Gaussian processes, with applications to electrical and computer engineering at a rigorous level. Three term-hours; lectures. S. Gazor

ELEC 863 Topics in Optical Communications
Selected topics in optical communications will be studied. Possible topics include semiconductor lasers, optical modulators, modulation formats, multiplexing and demultiplexing techniques, optical fibers, dispersion compensation, optical amplifiers, optical receivers, system performance, optical time division multiplexing, optical signal processing (e.g., wavelength conversion, optical regeneration, clock recovery), passive components, optical networks, and applications (e.g., access, metro, long-haul, ultra-long haul). Three term-hours, lectures, Fall. J.C. Cartledge

ELEC 864 WDM Fiber Optic Communication Systems
This course presents the fundamentals of fiber optic communications, with focus on dense wavelength division multiplexed (DWDM) systems. Topics: components (lasers, modulators, receivers, and optical fibers) and detailed study of system issues in DWDM transmission (interplay between fiber dispersion and non-linearities, transmitter chirp, optical amplification, and polarization mode dispersion). Three term hours, lectures. S. Yam

ELEC 865 Coding Theory
The problem of reliable data transmission; communication and coding; error-detecting and error-correcting codes; classification of codes; introduction to algebra; linear block codes; cyclic codes; algebraic decoding,shift register encoding and decoding of cyclic codes; convolutional codes; Viterbi decoder; trellis codes; trellis decoding, trellis structure of codes; graphical representation ofcodes, block- and trellis-coded modulation, codes defined on graphs, turbo codes, iterative decoding, low-density parity-check codes. Three term-hours, lectures. S. Yousefi

ELEC 866 Signal Detection and Estimation
Vector space concepts. Hypothesis testing. Signal detection in discrete time including performance evaluation methods and sequential detection. Parameter estimation, including Bayesian, maximum-likelihood and minimum-variance unbiased estimation. Signal estimation in discrete time, including Kalman filtering, linear estimation, and Wiener filtering. Applications include communications, sensor array, image processing, and target tracking. Three term-hours; lectures. S.D. Blostein.

ELEC 867 Data Communication
Channel characterization and transmission impairments, performance evaluation, baseband pulse transmission, linear modulation, frequency and phase modulation, detection theory and system optimization, equalization, coded modulation.

ELEC 869 MIMO Communications Systems
This course introduces fundamental theories of multiple-input multiple-output (MIMO) communications systems and design of space-time codes. Topic includes: MIMO channel models; capacity of MIMO systems; transmit and receive diversity; design criteria for space-time codes; space-time block codes; space-time trellis codes; layered space-time codes; differential space-time block codes; combined space-time codes and interference suppression; super-orthogonal space-time codes; variable rate space-time block codes. Three term-hours, lectures. I. Kim

ELEC 870 Human-Robot Interaction
This course focuses on the study and design of human-robot interactions (HRIs). Students will gain exposure to a broad cross-section of HRI research, exploring topics such as sensors and actuators, software architectures and design and evaluation tools. Selected HRI subdomains will be examined, including nonverbal communication, trust, and ethics. (3.0 credit units)
PREREQUISITE: ELEC 344 or similar course.
CO-REQUISITES: ELEC 448 or MECH 456 or MREN 348 or similar from another university, OR permission of the instructor.

ELEC 871 Shared-Memory Multiprocessor Systems
This course provides a comprehensive overview of shared-memory multiprocessing. Topics include: shared-memory programming, system and application software considerations, cache coherence protocols, memory consistency models, small-scale and large-scale shared-memory architectures, and case studies to explore practical

considerations in multiprocessor systems ranging from single-chip implementations to scalable high-performance platforms. Three term hours; lectures. Winter. N. Manjikian

ELEC 872 Artificial Intelligence and Interactive Systems
Fundamental concepts and applications of intelligent and interactive system design and implementation. Topics include: (1) Sensors and Signals in Interactive Systems (2) Data Preprocessing: data acquisition, filtering, missing data, source separation, feature extraction, feature selection, dimensionality reduction; (3) Machine Learning: supervised learning, ensemble learning, multi-task learning, unsupervised learning; (4) Identity Recognition; (5) Activity Recognition and Analysis; (6) Affective Computing. Three term hours. Lectures. A. Etemad
PREREQUISITE: ELEC 326 or equivalent, or permission of the instructor.

ELEC 873 Cluster Computing
This course covers topics related to network-based parallel computing systems. Issues related to clusters and computational "grid" such as interprocessor communications, message-passing and mixed mode paradigms and programming techniques, high performance interconnects, efficient host-network interface for fast messaging, lightweight user-level messaging layers and protocols, (network interface-assisted based) collective communications, communication latency tolerance techniques, power-aware high-performance computing, high performance file systems and I/O, benchmarking and performance evaluation, scheduling and load balancing, system-level middleware and computational grid applications and services will be discussed, Research papers from literature, a term paper and hands-on programming and experiments on a network of workstations will supplement the course. Three term-hours; lectures. A. Afsahi

ELEC 874 Deep Learning in Computer Vision
This course will study advances in Deep Learning as applied to the field of Computer Vision. The course will start with the introduction of AlexNet in 2012, and will advance chronologically, exploring the innovations that led to the significant improvements in performance. Topics covered will include object detection and recognition, region proposal networks, instance and semantic segmentation, depth and video processing. Three term hours, lectures. M. Greenspan
PREREQUISITES: ELEC 474, ELEC 425 or equivalent, or permission of instructor.

ELEC 875 Software Design Recovery and Automated Evolution
Design recovery is the extraction of a design model from the artifacts of an existing software system. This design model is used to continue the evolution of the system. The model can be used in the planning and impact analysis stage, while making the changes and to test the result. The extracted design model can also be used to automate each of these tasks to varying degrees. Topics include design models, design recovery techniques, software evolution tasks, the semantics of programming languages and execution environments, and source code transformation. Three term-hours, lectures, Winter, T. Dean.

ELEC 876 Software Reengineering
This course covers software reengineering techniques and tools that facilitate the evolution of legacy systems. This course is broken into three major parts. In the first part, the course discusses the terminology and the processes pertaining to software evolution. In the second part, the course provides the fundamental reengineering techniques to modernize legacy systems. These techniques include source code analysis, architecture recovery, and code restructuring. The last part of the course focuses on specific topics in software reengineering research. The topics include software refactoring strategies, migration to Object Oriented platforms, quality issues in reengineering processes, migration to network-centric environments, and software integration. Three term-hours, lectures, Fall, Y. Zou

ELEC 877 AI for Cybersecurity
This course covers the fundamentals of cybersecurity and machine learning, selected topics in machine learning for cybersecurity, including anomaly detection, malware analysis, network traffic analysis, and fake news defense, and the advanced topics in artificial intelligence (AI) security, including privacy-preserving AI, fairness in AI, and adversarial machine learning. Three term hours, Lectures. J. Ni.
PREREQUISITE: ELEC 425 or equivalent, or permission of the instructor

ELEC 878 Extreme Scale Networking
This course will provide students with understanding of the field of Extreme-scale Systems with an emphasis on Extreme-Scale networks. Students will learn the fundamentals of Extreme-scale systems networks and an ability to read, understand, discuss and critique research. Use cases like Scientific computing, AI/ML, big data and commercial applications will be discussed. (3.0 credit units).
PREREQUISITE: ELEC 373 (networks) or equivalent. Pre-requisites may be waived with permission of the instructor.

ELEC- 879 Wearable and IoT Computing
This course focuses on recent advances and computing trends in wearable technologies, mobile devices, the Internet of Things (IoT), smart homes, and smart vehicles. The history, background, and applications of these systems are reviewed, followed by the description of common sensing technologies often utilized in these devices. Signal/time-series analysis

techniques, machine learning algorithms, and computing methods that are often utilized in such applications will be covered in detail. The course is highly applied and students will complete a project and present their results.

ELEC 880 Machine Learning for Natural Language Processing
Human (or natural) language data permeate almost all aspects of our daily life. This course covers basic machine learning approaches to modelling natural language, including fundamental supervised and unsupervised methods for modelling sequences and structures in the data. Based on this, students learn how to develop various applications such as chatbots and information extraction systems. The course will also include state-of-the-art artificial intelligence and deep learning approaches to natural language processing.

ELEC 891 Seminar
ECE graduate students must register in this non-credit course for the duration of their degree program. The student is given a Pass grade for this course upon attending a majority of seminars designated by ECE.

ELEC 895 Industrial Internship I
The industrial internship involves spending a minimum of 4 months and a maximum of 8 months in a paid internship position in industry, government, or other suitable employment opportunities. Students in the 4 month internship must register in ELEC 895. Students in the 8 month internship must register in ELEC 895 and ELEC 896. Successful completion of the course requires submission of a report on the industrial project within thirty days of completion of the work period. Each project must be approved by the academic supervisor. Career Services manages the non-academic aspects of the course.

ELEC 896 Industrial Internship II
See ELEC 895.

ELEC 898 M.Eng. Project

ELEC 899 M.Sc. Thesis Research

ELEC 999 Ph.D. Thesis Research

ADVANCED UNDERGRADUATE ELECTIVE COURSES
Courses listed below may be taken for credit, subject to the regulations set forth in the departmental prescription above and those of the School of Graduate Studies.
ELEC 421, 431, 436, 443, 448, 451, 454, 461, 464, 470, 471, 476, 478, 483, 486, 487, SOFT-423, 426, 437.