

Department of Electrical and Computer Engineering

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<http://www.odu.edu/ece/> (<http://eng.odu.edu/ece/>)

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Department Description

The Department of Electrical and Computer Engineering strives to provide the highest quality engineering education at the undergraduate and graduate levels, to engage in scholarly research at the forefront of electrical, computer, and biomedical engineering, and to serve the professions of electrical, computer, modeling and simulation, and biomedical engineering. The department has strong graduate and research programs providing a high quality and broad-based education that prepares graduates for successful professional careers and a lifetime of learning. The Electrical & Computer Engineering Department also offers a Doctor of Engineering Degree in Cybersecurity. *This program is available on-campus and online.*

Electrical and Computer Engineering graduate studies encompass six broad areas:

1. systems
2. signal and image processing
3. physical electronics
4. computer engineering
5. cybersecurity engineering
6. modeling and simulation engineering

Special Facilities

The research laboratories and institutes directly associated with the department include:

- Applied Plasma Technology Laboratory (APTL)
- CAVE Automated Virtual Environment (CAVE)
- Collaborative Autonomous Systems Laboratory
- Cybersecurity, Communications & Networking Innovation (CCNI) Laboratory
- Gene Therapy and Regenerative Medicine Laboratory
- Medical Imaging, Diagnosis & Analysis (MIDA) Laboratory
- Medical Simulations Laboratory
- Plasma Engineering & Medicine Institute (PEMI)
- Systems Research Laboratory
- Virginia Institute for Photovoltaics (VIPV)
- Vision Lab
- Virginia Institute for Vision Analysis (VIVA)

In addition, the department has several faculty with research labs at the Applied Research Center (ARC) at the Jefferson National Laboratory. The ARC facilities include thin film fabrication equipment for applications in photovoltaics, thermoelectrics, superconductors, and semiconductors. ARC houses extensive materials analysis capabilities. All of these research facilities position the department for national leadership in several areas and as a leading institution of research and higher education in the

southeastern United States. In addition, the faculty have strong ties to the Jefferson Laboratories, Frank Reidy Center for Bioelectronics, the Center of Bioelectronics, and the Virginia Modeling, Analysis, and Simulation Center (VMASC).

List of Degrees and Certificate

The department offers the following Electrical and Computer Engineering graduate degrees:

- Master of Science, Engineering - Electrical and Computer Engineering (Traditional and Online Formats)
- Doctor of Philosophy, Engineering - Electrical and Computer Engineering
- Doctor of Engineering, Electrical and Computer Engineering,
- Doctor of Engineering, Cybersecurity

and

- Master of Science, Engineering - Modeling and Simulation
- Doctor of Philosophy, Engineering - Modeling and Simulation
- Doctor of Engineering - Modeling and Simulation
- Graduate Certificate in Modeling and Simulation Engineering

The department also administers the following Biomedical Engineering graduate degrees and a certificate.

- Master of Engineering - Biomedical Engineering
- Master of Science, Engineering - Biomedical Engineering
- Doctor of Philosophy, Engineering - Biomedical Engineering
- Advanced Engineering Certificate - Biomedical Engineering

Master of Science, Engineering, Electrical and Computer Engineering

Degree Description

The Department offers a Master of Science (M.S.) in Engineering degree with a concentration in Electrical & Computer Engineering. It requires a minimum of 30 credit hours of graduate study. The credit hours are obtained through a combination of graduate coursework and thesis research. Full-time and part-time students may complete coursework through a combination of on-campus and distance learning courses. The distance learning courses are available synchronously at the higher education centers and can be broadcast to any computer with a high speed Internet connection. Full details on all requirements for graduating with a Master's degree are outlined in a separate section that follows the admission information.

Admission Information

Applicants are expected to hold a B.S. degree in electrical engineering (EE) or computer engineering (CpE) from an accredited institution. Applicants are also expected to have a minimum grade point average of 3.0 (on a 4.0 scale) in both the baccalaureate major area (EE or CpE) and overall. Applicants with a GPA below a 3.0 may be considered for provisional admission, which may require additional prerequisite courses in addition to the graduate degree requirements. The applications are submitted through the Office of Admissions of Old Dominion University. Together with the completed application form, two letters of recommendation from former instructors or employment supervisors, transcripts from all colleges and universities attended, GRE scores, a resume, and a personal statement of objectives are required. TOEFL scores are also required for international applicants. Applicants with academic degrees in areas other than electrical and computer engineering will be considered. Those with degrees in math, physics, computer science, or other engineering fields are encouraged to apply. The linked Bachelor's/Master's degree program in the Frank Batten College of Engineering and Technology at Old Dominion University is designed to provide an opportunity for exceptionally qualified engineering undergraduate students to obtain both a bachelor's and a master's degree in Electrical and Computer Engineering. Typically undergraduate students apply at the end of their junior year for admission to the linked programs.

Accepted students from disciplines other than EE or CpE are required to complete a number of leveling courses to meet prerequisites for graduate studies. All students are required to have one year of college chemistry and one year of calculus-based college physics in addition to Calculus III and Differential Equations courses. Students at Old Dominion University may complete the leveling requirement by earning a minor in electrical or computer engineering with a GPA of 3.0 or greater. Students that have not earned a minor need to meet with the graduate program director to prepare a course plan and determine which pre-requisite courses are needed. In general, three to four leveling courses are needed and they are chosen from the following lists.

List of Possible Courses to Meet the Leveling Requirement

ECE 202	Circuit Analysis II	3
ECE 241	Fundamentals of Computer Engineering	4
ECE 302	Linear System Analysis	3
ECE 303	Introduction to Electrical Power	3
ECE 304	Probability, Statistics, and Reliability	3
ECE 313	Electronic Circuits	4
ECE 323	Electromagnetics	3
ECE 332	Microelectronic Materials and Processes	3
ECE 341	Digital System Design	3
ECE 346	Microcontrollers	3
ECE 381	Introduction to Discrete-time Signal Processing	3

Students interested in taking computer engineering graduate courses may need to take additional leveling computer science courses as indicated below.

List of Possible Computer Science Courses to Meet the Leveling Requirements

CS 350	Introduction to Software Engineering	3
CS 361	Data Structures and Algorithms	3
CS 381	Introduction to Discrete Structures	3

Degree Requirements

The M.S. degree requires a minimum of 30 credit hours of graduate study.

The M.S. degree thesis option requires a minimum of 24 credit hours of courses (not including the Graduate Seminar), at least 1 credit hour of Graduate Seminar (ECE 731), and 6 credit hours of thesis along with the oral thesis defense examination. Continuation in the M.S. program thesis option is contingent upon identifying a MS thesis advisor after completing 18 credit hours of coursework (which coincides approximately with the end of the second semester of study for full-time students). For the thesis committee, the chair has to be a full time ECE faculty member as well as a minimum of 2 full time ECE faculty members and 1 outside ECE member are required.

The M.S. degree project option requires a minimum of 27 credit hours of courses (not including the Graduate Seminar) and 3 credit hours of Master's project course (ECE 698) that includes an oral defense examination.

The M.S. degree course option requires a minimum of 30 credit hours of courses (not including the Graduate Seminar) and a written comprehensive examination at the end of the course work. The examination is offered every fall and spring semesters, and the student needs to pass the examination in no more than two attempts. The second attempt, if necessary, should be taken at the next offered examination.

The M.S. program is available to full-time and part-time students seeking to improve their professional skills in electrical and computer engineering. Students are required to complete at least one course that meets the department's mathematics requirement. The current list of courses that meet this requirement is given next.

ECE 601	Linear Systems	3
ECE 611	Numerical Methods in Engineering Analysis	3
ECE 623	Electromagnetism	3
ECE 651	Statistical Analysis and Simulation	3

The remaining courses are chosen to meet the student's career objectives. To earn a master's degree, a student needs to take at least five courses at the 600 or higher level, and no more than three courses at the 500 level. Also, no more than three graduate courses can be taken in other departments. All course selections must be reviewed by the graduate program director, and for M.S. thesis option students' course selection should be made in coordination with the students' research/thesis advisor. The graduate course descriptions are included in the graduate catalog and are also listed on the department's website. Additional graduate courses are offered through the Commonwealth Graduate Engineering Program and the Virginia Consortium for Engineering and Science. All funded Master's students are required to attend Graduate Seminar (ECE 731).

Doctor of Philosophy, Engineering-Electrical and Computer Engineering

Degree Description

The Department offers a strong doctoral program leading to the Doctor of Philosophy (Ph.D.) in Engineering degree with a concentration in Electrical and Computer Engineering. The Ph.D. degree is awarded to candidates who have displayed an in-depth understanding of the subject matter and demonstrated the ability to make an original contribution to knowledge in their chosen field of specialty. A very important component of the Ph.D. degree is the original research pursued by the student which culminates in a written dissertation, as well as an oral defense of this work. Ph.D. students usually publish the result of their research in highly reputable nationally and internationally refereed journals. In addition, the students are expected to present their work at national and international conferences.

Admission Requirements

Applicants to a doctoral degree in electrical and computer engineering are expected to have completed a master's degree in electrical engineering and/or computer engineering or a closely related technical field with a minimum grade point average of 3.5 (on a 4.0 scale) in graduate course work.

The applications are submitted through the Office of Admissions of Old Dominion University. Together with the completed application form, three letters of recommendation, transcripts from all colleges and universities attended, GRE scores, a resume, and a personal statement of objectives are required. TOEFL scores are required for international applicants. At least two of the recommendation letters should be submitted by faculty or work supervisor familiar with the applicant's graduate work. The Frank Batten College of Engineering and Technology at Old Dominion University has the Direct Bachelor-to-Ph.D. and Integrated Bachelor/Ph.D. programs that allow exceptionally well-qualified undergraduate students to apply for admission directly to a Ph.D. program. The programs are described in the college section of the catalog.

Degree Requirements

The Ph.D. degree requires:

- 24 credit hours of graduate-level courses beyond the master's degree (not including Graduate Seminar),
- 24 research credit hours,
- successful completion of a written diagnostic examination,
- successful completion of written and oral candidacy examinations,
- successful completion of a dissertation research proposal, and
- successful completion and public defense of a dissertation.
- Or, in the absence of a master's degree, 78 credit hours (not including Graduate Seminar) beyond the bachelor's degree are required.

For students with a master's degree, the 24 credit hours of graduate-level coursework consist of 8 graduate level courses that are chosen by the student together with the research advisor and are approved by the Graduate

Program Director. Of the 8 courses, 5 must be completed at the 800 level, and no more than 3 graduate courses can be taken in other departments. For students without a master's degree, the 78 credit hours of graduate level coursework consist of 48 credit hours of graduate courses and 30 research credit hours (ECE 899). Three fifths of the required 78 credit hours must be at the 800 level and need to comply with regular PhD program degree requirements. The Graduate Program Director, in concurrence with the Chair, can approve exceptions to these requirements under special circumstances. Additional course work or appropriate research background may be required to meet prerequisites for courses or in preparation for the diagnostic examination. Furthermore, at least 1 credit hour of Graduate Seminar (ECE 831) is required, and all funded students are required to attend Graduate Seminar. The graduate course descriptions are included in the catalog and are also listed on the department's website. Additional graduate courses are offered through the Commonwealth Graduate Engineering Program.

All Ph.D. students are required to take the department's Ph.D. Diagnostic Examination for the first time before the end of their second semester in the Ph.D. program. The examination is offered every fall and spring semester, and the student needs to pass the examination in no more than two attempts. The second attempt, if necessary, should be taken at the next offered examination. The topics for the examination and samples of previous examinations are posted in the department's website. The examination rules are given on the first page of each examination.

It is required that the written and oral candidacy examinations be taken in the semester when a student is completing the graduate course work or during the following semester. Once a student has completed the course work, passed the candidacy examinations, and has gained approval for the research proposal, the student advances to candidacy. It is a University requirement that students who have advanced to candidacy be enrolled for at least one credit hour every fall, spring, and summer until graduation. For both advisory and dissertation committees, the chair has to be a full time ECE faculty member as well as a minimum of 2 full time ECE faculty members and 1 outside ECE member are required.

Doctor of Engineering, Electrical and Computer Engineering

The Department offers a Doctor of Engineering (D.Eng.) degree with concentration in Electrical and Computer Engineering in accordance with the admission criteria and degree requirements specified in the Frank Batten College of Engineering and Technology section in this catalog. The curriculum of this concentration consists of 18 credit hours of ECE 600 and 800 level courses as core courses, 18 credit hours of graduate coursework in the area of specialization and 12 credit hours of applied doctoral project. The courses need approval of the advisor and the graduate program director. Among the total 36 credit hours of coursework, no more than five graduate courses can be taken in other departments.

Cybersecurity Engineering Program

Chung-Hao Chen, Graduate Program Director, Doctor of Engineering, Cybersecurity
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Doctor of Engineering, Cybersecurity

The Department offers a Doctor of Engineering (D.Eng.) degree with concentration in Cybersecurity in accordance with the admission criteria and degree requirements specified in the Frank Batten College of Engineering and Technology section in this catalog. The curriculum of this concentration consists of 18 credit hours of CYSE, ECE, MSIM, or ENMA 600 and 800 level courses as core courses, 18 credit hours of graduate coursework in the area of specialization and 12 credit hours of applied doctoral project. The courses need approval of the advisor and the graduate program director. Of the total 36 credit hours of coursework, 15 credit hours need to be completed at the 800 level, and no more than 15 credit hours can be taken from disciplines other than CYSE, ECE, MSIM, or ENMA.

Master of Science, Engineering - Modeling and Simulation

The master's degree in modeling and simulation (M&S) emphasizes a strong, common subject core while providing the student with the flexibility to design a plan of study to meet each individual's study objectives and needs. The purpose of the program's subject core is to provide a common academic foundation for all simulation students. Thus, all students in this program will have grounding in the same methods, principles, and philosophy of simulation. This provides the mechanisms for the simulationist to work across disciplines and domains while maintaining a common frame of reference for communication, technical specialization, and advanced study and research. The Master of Science (MS) in Modeling and Simulation offers two options: Thesis Option and Course Option. The Thesis Option requires six hours of thesis credit and 24 hours of course credit and it is directed primarily at full-time students who are preparing for a career in advanced M&S research and/or academic positions. The Course Option requires 30 hours of course credit and it is focused on developing the practical skills and knowledge needed to solve problems requiring applications of modeling and simulation. The Course Option is further divided into two tracks: Development Track and Application Track. The Development Track is programming intensive and prepares students for advanced simulation development, while the Application Track focuses on the usage of existing advanced simulation tools.

The program's subject core consists of:

1. an overview of modeling and simulation;
2. an in-depth exploration of specific simulation methodological approaches;
3. simulation system modeling principles and techniques;
4. an introduction to computer visualization and visual simulation; and,
5. principles of stochastic analysis.

Most courses are offered in distance learning format. They are delivered to Old Dominion University's higher education centers and are available synchronously using video conferencing software.

Master of Science Admission Requirements

The Master's Degree in Modeling and Simulation is designed for students having bachelor's degrees in Engineering, Science or Mathematics, although students from other educational backgrounds may apply with appropriate leveling courses. Prerequisites for admission include: mathematics – two courses in differential and integral calculus and one course in calculus-based probability and statistics; and computer science – algorithmic problem solving using a high-level object-oriented programming language such as C++.

A minimum GPA of 2.80 overall and a minimum GPA of 3.0 in the undergraduate major are required. Students with notable deficiencies may be considered for provisional admission and will be required to complete prerequisite course requirements in addition to the graduate degree requirements. Job experience and training may be considered in evaluating prerequisite requirements.

Applicants should plan to submit a completed application form, transcripts from all colleges and universities attended, GRE scores (verbal, quantitative, and analytical writing - required of MS applicants for the thesis option only), a resume and personal statement of objectives, two letters of recommendation from former university instructors or current employer (recommendation letters are required of MS applicants for the thesis option only), and TOEFL scores if an international applicant.

Potential prerequisite courses for the master's degrees in modeling and simulation include the following:

1. Introductory differential and integral calculus equivalent to MATH 211 (<https://catalog.odu.edu/search/?P=MATH%20211>) (Calculus I) and MATH 212 (<https://catalog.odu.edu/search/?P=MATH%20212>) (Calculus II).
2. Calculus-based probability and statistics; this material is available for graduate credit in PSYC 727 (<https://catalog.odu.edu/search/?P=PSYC>)

%20727). Undergraduate courses STAT 330 (<https://catalog.odu.edu/search/?P=STAT%20330>) or ENMA 420 (<https://catalog.odu.edu/search/?P=ENMA%20420>) will also meet the prerequisite requirement.

- Computer science fundamentals including an object-oriented programming language such as C++, algorithmic problem solving, and data structures.

Master of Science Degree Requirements

The Master of Science program requires 12 hours of course credit in modeling and simulation foundation courses. These foundation courses include:

MSIM 741	Principles of Visualization	3
MSIM 551	Analysis for Modeling and Simulation	3
or MSIM 751	Advanced Analysis for Modeling and Simulation	
Advanced Modeling Course (See List Below)		3
Advanced Simulation Course (See List Below)		3

Advanced Modeling Course Examples (3 credits)

MSIM 607	Machine Learning I
MSIM 660	System Architecture and Modeling
MSIM 702	Systemic Decision Making
MSIM 730	Simulation Formalisms
MSIM 772	Modeling Global Events
MSIM 774	Transportation Network Flow Models

Other courses with Graduate Program Director's approval.

Advanced Simulation Course Examples (3 credits)

MSIM 711	Finite Element Analysis
MSIM 722	Cluster Parallel Computing
MSIM 725	Principles of Combat Modeling and Simulation
MSIM 742	Synthetic Environments
MSIM 776	Simulation Modeling in Transportation Networks

Other courses with Graduate Program Director's approval.

The remaining course credits (12 credits for the thesis option and 18 credits for the course option) are elective course credits. These courses are selected to achieve one or more program objectives or themes and must be approved by the student's advisor and/or graduate program director. Elective courses outside the CMSE Department must be approved by the graduate program director. The thesis option concludes with 6 credit hours of thesis credit (MSIM 699 (<https://catalog.odu.edu/search/?P=MSIM%20699>)) and a thesis defense and the course option concludes with a comprehensive exam.

Students must also complete the Responsible Conduct of Research for Engineers training online.

Certain students will need to take pre-requisite leveling courses that will count towards the 12 credit hour elective course requirement. These courses are: MSIM 510 (<https://catalog.odu.edu/search/?P=MSIM%20510>) Model Engineering; MSIM 541 (<https://catalog.odu.edu/search/?P=MSIM%20541>) Computer Graphics and Visualization; MSIM 602 (<https://catalog.odu.edu/search/?P=MSIM%20602>) Simulation Fundamentals; and, MSIM 603 (<https://catalog.odu.edu/search/?P=MSIM%20603>) Simulation Design. The Course Option Application Track only requires MSIM 510 (<https://catalog.odu.edu/search/?P=MSIM%20510>) Model Engineering and MSIM 602 (<https://catalog.odu.edu/search/?P=MSIM%20602>) Simulation Fundamentals as leveling courses.

The MS Course Option is also offered online via the Blackboard Academic Suite and WebEx that provides online lectures, homework submissions, examinations, discussion boards, wikis, video/audio collaboration sessions and grading. Students having access to reliable high speed internet service can connect and participate in engaging discussion and distributed asynchronous learning with the instructor and other students. All course materials are distributed and collected electronically. Students located in the

Hampton Roads region may utilize live courses to fulfill the elective course requirement with approval from the CMSE graduate program director.

Doctor of Engineering - Modeling and Simulation

The D. Eng. in Modeling and Simulation program focuses on developing the advanced skills and knowledge to enable the graduate to conduct and lead advanced technical M&S projects in an engineering environment. It affords engineering practitioners the opportunity to achieve advanced graduate education beyond the master's degree.

For complete information on admission requirements and core degree requirements, please refer to the Doctor of Engineering program information at: <http://catalog.odu.edu/graduate/frankbattencollegeofengineeringandtechnology/#doctorofengineeringprogram>

The program of study for the D.Eng. in M&S program is developed with the approval of the graduate program director and the student's advisor. The program shall include a minimum of 18 credits of professional course work (<http://catalog.odu.edu/graduate/frankbattencollegeofengineeringandtechnology/#doctorofengineeringprogram>). The course ENGN 812 Engineering Leadership is cross-listed with the course ENMA 880 ENMA 880 ENMA 880 ENMA 880 Leadership for Engineering Managers and ENGN 612 Analysis of Organizational Systems is cross-listed with ENMA 601 (<https://catalog.odu.edu/search/?P=ENMA%20601>) Analysis of Organizational Systems. Other professional courses can be substituted by other courses approved by the Graduate Program Director if these professional courses are not available.

The D.Eng. also requires 18 credits of technical core course work beyond the master's degree distributed as follows:

Technical Core Courses

Advanced Simulation Course from the list below

MSIM 830	Simulation Formalisms
MSIM 842	Synthetic Environments
MSIM 851	Advanced Analysis for Modeling and Simulation

Two approved technical elective courses - 6 credits

Advanced Simulation Course Examples (3 credits)

MSIM 811	Finite Element Analysis
MSIM 822	Cluster Parallel Computing
MSIM 825	Principles of Combat Modeling and Simulation
MSIM 876	Simulation Modeling in Transportation Networks

Other courses with Graduate Program Director's approval.

No more than three credits from course work satisfying foundation knowledge requirements may be included in the program of study for technical elective credit. At least three-fifths of the non-project coursework must be at the 800-level.

Certain students entering the program will be required to complete additional pre-requisite leveling courses. These courses are: MSIM 510 Model Engineering; MSIM 541 Computer Graphics and Visualization; MSIM 602 MSIM 602 MSIM 602 Simulation Fundamentals; and MSIM 603 Simulation Design.

For graduation, students must complete the requirements for their final project and the Responsible Conduct of Research for Engineers training online.

Doctor of Philosophy, Engineering - Modeling and Simulation

The Ph.D. in Modeling and Simulation program focuses on developing the necessary skills and knowledge to enable the graduate to conduct and evaluate independent, original research in an area of modeling and simulation. The goal of the program is to prepare students for careers in teaching and research at academic institutions, as well as the conduct or leadership of research and development in public and private organizations.

Doctor of Philosophy Admission Requirements

Admission to the Ph.D. in M&S program is made in accordance with Old Dominion University and Batten College of Engineering and Technology requirements for doctoral programs as specified in this Catalog. Specific requirements for the modeling and simulation degree include the following:

1. Completion of a master's degree in an appropriate and closely related field is expected. However, students who have completed 24 credits of graduate courses in an appropriate field from an accredited institution may apply.
2. A minimum GPA in graduate course work of 3.50 (out of 4.0) is required of most students. A student with a GPA greater than 3.25 and with evidence of a high level of professional capability in the field of modeling and simulation may be eligible for admission to the program upon submission of a petition to the graduate program director.
3. Recent scores (typically, not more than five years old) on the Graduate Record Examination's (GRE) verbal, quantitative, and analytical writing sections must be submitted by all applicants.
4. Three letters of recommendation (typically at least two of which are from faculty in the highest degree program completed when the application is within five years of graduation from that degree program) are required.
5. The applicant must submit a statement of purpose, goals, and objectives related to the program and a resume.

Applicants are expected to have the following foundation knowledge:

1. Mathematics fundamentals including differential and integral calculus, ordinary differential equations, calculus-based probability and statistics, and linear algebra.
2. Computer science fundamentals including an object-oriented programming language such as C++, algorithmic problem solving, and data structures.
3. Knowledge of the content of the foundation courses required in the Modeling and Simulation Master's Program.

Doctor of Philosophy Degree Requirements

The Ph.D. in modeling and simulation is offered in accordance with the general requirements for doctoral degrees as specified in the Requirements for Graduate Degrees Section of this Catalog. Specific program of study requirements for the concentration in modeling and simulation include the following:

1. Completion of a minimum of 24 credits of course work beyond the master's degree; and a minimum of 24 credits of dissertation research.
2. Successful completion of a written diagnostic examination before completion of nine credits of advanced course work.
3. Successful completion of a written and oral qualifying (candidacy) examination near the completion of the course work.
4. Successful presentation of a dissertation research proposal at the beginning of the dissertation research.
5. The successful completion and public defense of a dissertation representing independent, original research worthy of publication in a peer-reviewed scholarly journal.

The program of study for the Ph.D. in M&S program is developed with the approval of the graduate program director and the student's advisor. The program shall include a minimum of 24 credit hours of course work beyond the master's degree distributed as follows.

Common Core

Advanced Simulation Course (see the list below)	3	
MSIM 830	Simulation Formalisms	3
MSIM 842	Synthetic Environments	3
MSIM 851	Advanced Analysis for Modeling and Simulation	3
Total Hours		12

Advanced Simulation Course Examples (3 credits)

MSIM 811	Finite Element Analysis
MSIM 815	High Performance Computing and Simulations
MSIM 822	Cluster Parallel Computing
MSIM 825	Principles of Combat Modeling and Simulation
MSIM 876	Simulation Modeling in Transportation Networks
Other courses with graduate program director's approval.	

Electives - Minimum of 12 credits of elective courses that provide a basis for dissertation research. No more than six credits from course work satisfying foundation knowledge requirements may be included in the program of study for elective credit. At least three-fifths (15 credits) of non-dissertation course work must be at the 800-level. Elective courses outside the MSVE Department must be approved by the graduate program director.

Certain students entering the program will be required to complete additional pre-requisite leveling courses. These courses are: MSIM 510 Model Engineering; MSIM 541 Computer Graphics and Visualization; MSIM 602 Simulation Fundamentals; and MSIM 603 Simulation Design.

For graduation, students must successfully defend their dissertation and complete the Responsible Conduct of Research for Engineers training online.

Graduate Certificate in Modeling and Simulation Engineering

The Graduate Certificate in Modeling and Simulation Engineering is designed for those who meet the admission requirements of the modeling and simulation master's program and wish to broaden their knowledge of modeling and simulation related principles and practices without pursuing a graduate degree. This is a 12 credit hour non-degree program offered by the Department of Computational Modeling & Simulation Engineering. The certificate program is open to both degree-seeking and non-degree-seeking graduate students. Certain courses taken for the certificate program may later be applied to the master's degree in modeling and simulation.

Graduate Certificate Admission Requirements

Students should have either an undergraduate degree from a regionally accredited institution and should have a mathematical background through calculus, along with a calculus based probability and statistics course. Students should submit a graduate non-degree application through the Office of Admissions, and then submit a departmental application with copies of unofficial transcripts from all previous coursework to the CMSE Department. Departmental applications are available online on the CMSE Department's website – <https://www.odu.edu/cmse> (<https://www.odu.edu/cmse/>) - and should be sent to:

Academic Advisor and Program Manager
 CMSE Department
 Old Dominion University
 1300 Engineering and Computational Sciences Building
 Norfolk, VA 23529

Graduate Certificate Course Requirements

The Graduate Certificate in Modeling and Simulation Engineering requires the completion of 12 credit hours at the graduate level. The course requirements are:

Select three courses from the following:	9
MSIM 601 Introduction to Modeling and Simulation	
MSIM 602 Simulation Fundamentals	
MSIM 510 Model Engineering	
MSIM 603 Simulation Design	
MSIM 541 Computer Graphics and Visualization	
MSIM 551 Analysis for Modeling and Simulation	
MSIM Elective *	3
Total Hours	12

* A graduate level elective approved by the Graduate Program Director. This elective may be an MSIM course or from another discipline outside of modeling and simulation. It is possible that this course may be outside of the discipline of modeling and simulation, but approved because it complements the field of modeling and simulation and the student's interests.

An overall GPA of 3.0 or better is required to earn the graduate certificate in modeling and simulation engineering.

Biomedical Engineering Program

Michel Audette, Graduate Program Director

1321 Engineering and Computational Science Building
757-683-6940
www.odu.edu/eng/programs/biomedical/

The Biomedical Engineering graduate degree programs are available to full-time and part-time students seeking to improve their research and professional skills in biomedical engineering. The programs strive to provide the highest quality engineering education at the graduate level, to engage in scholarly research at the forefront of biomedical engineering, and to serve the profession of biomedical engineering. While the biomedical engineering program is administered by the Department of Electrical & Computer Engineering, the program is highly interdisciplinary and students are admitted from broad areas of engineering, science, and healthcare. Cutting-edge research opportunities and instruction are offered in:

- Bioelectrics and Pulsed Power
- Cellular & Molecular Bioengineering
- Cardiovascular Engineering
- Medical Image Analysis and Simulation
- Musculoskeletal Biomechanics
- Plasma Medicine
- Systems Biology & Computational Bioengineering

Facilities: The Biomachina Laboratory; the Biomechanics Laboratory; the Cardiac Electrophysiology Laboratory; the Cellular Mechanobiology Laboratory; the Medical Imaging, Diagnosis and Analysis (MIDA) Laboratory; the Gene Therapy and Regenerative Medicine Laboratory; the Medical Simulations Laboratory; the Plasma Engineering and Medicine Institute (PEMI); and the Virginia Institute for Imaging and Vision Analysis (VIIVA).

The program also has strong ties to several other on- and off-campus laboratories including the Applied Research Center at the Jefferson National Laboratory, the Center for Brain Research and Rehabilitation, the Frank Reidy Research Center for Bioelectrics, and the Virginia Modeling, Analysis and Simulation Center (VMASC). The program is supported by regional, national, and international clinical collaborators. These unique resources position the biomedical engineering program to be a leader in education and research in the Southeast and nationally.

Master of Engineering - Biomedical Engineering

Master of Engineering Admission Requirements

Admission to the Master of Engineering program in biomedical engineering is in accordance with Old Dominion University and Frank Batten College of Engineering and Technology requirements for master's programs as specified in this catalog. Specific additional requirements include the following:

1. Completion of a bachelor's degree in Engineering, Science or Mathematics from an accredited institution, although students from other educational backgrounds may apply with appropriate leveling courses.
2. A minimum GPA of 3.00 (out of 4.0) is required of most students. A student with a lower GPA meeting ODU's graduate admission requirements and with evidence of a high level of professional capability may be eligible for admission to the program upon submission of a petition to the graduate program director.
3. Recent scores, typically, not more than five years old, on the Graduate Record Examination's (GRE) verbal, quantitative, and analytical writing sections must be submitted by all applicants.
4. Two letters of recommendation (typically from faculty in the highest degree program completed when the application is within five years of graduation from that degree program) are encouraged but not required.
5. The applicant must submit a resume and a statement of purpose and goals.
6. Foundation knowledge in physics, basic chemistry, physiology, computer programming, and mathematics (including differential equations and statistics) is expected. Some leveling courses may be required to complement the student's expertise, namely in physiology, statistics, and differential equations.
7. The linked Bachelor's/Master's degree program in the Frank Batten College of Engineering and Technology at Old Dominion University is designed to provide an opportunity for exceptionally qualified engineering undergraduate students to obtain both a bachelors and a master's degree in Biomedical Engineering. Typically, undergraduate students apply at the end of their junior year for admission to the linked programs.

BME Common Core (Choose Three)	9
BME 720 Modern Biomedical Instrumentation	
BME 721 Mathematical Modeling in Physiology	
BME 726 Biomaterials	
BME 792 Biomechanics	
BME Technical Electives (Choose Four)	12
BME 554 Introduction to Bioelectrics	
BME 562 Introduction to Medical Image Analysis	
BME 564 Biomedical Applications of Low Temperature Plasmas	
BME 612 Digital Signal Processing I	
BME 720 Modern Biomedical Instrumentation	
BME 721 Mathematical Modeling in Physiology	
BME 724 Neural Engineering	
BME 740 Regenerative Medicine	
BME 751 Computational and Statistical Methods in Biomedical Engineering	
BME 762 Applied Medical Image Analysis	
BME 783 Digital Image Processing	
BME 795 Special Topics in Biomedical Engineering	
Approved Technical Electives *	9
Total Hours	30

* The technical elective courses can be selected from the biomedical engineering technical electives or a wide

variety of appropriate graduate courses in engineering, biology, chemistry, psychology, computer science, modeling and simulation, mathematics, statistics, or other programs. Technical electives without the BME prefix must be approved by the graduate program director.

Master of Science, Engineering - Biomedical Engineering

Master of Science Admission Requirements

Admission to the Master of Science, Engineering - Biomedical Engineering program is in accordance with Old Dominion University and Frank Batten College of Engineering and Technology requirements for master's programs as specified in this catalog. Specific additional requirements include the following:

1. Completion of a bachelor's degree in Engineering, Science or Mathematics from an accredited institution, although students from other educational backgrounds may apply with appropriate leveling courses.
2. A minimum GPA of 3.00 (out of 4.0) is required of most students. A student with a lower GPA meeting ODU's graduate admission requirements and with evidence of a high level of professional capability may be eligible for admission to the program upon submission of a petition to the graduate program director.
3. Recent scores, typically, not more than five years old, on the Graduate Record Examination's (GRE) verbal, quantitative, and analytical writing sections must be submitted by all applicants.
4. Two letters of recommendation (typically from faculty in the highest degree program completed when the application is within five years of graduation from that degree program) are encouraged but not required.
5. The applicant must submit a resume and a statement of purpose and goals.
6. Foundation knowledge in physics, basic chemistry, physiology, computer programming, and mathematics (including differential equations and statistics) is expected. Some leveling courses may be required to complement the student's expertise, namely in physiology, statistics, and differential equations.
7. The linked Bachelor's/Master's degree program in the Frank Batten College of Engineering and Technology at Old Dominion University is designed to provide an opportunity for exceptionally qualified engineering undergraduate students to obtain both a bachelor's and a master's degree in Biomedical Engineering. Typically, undergraduate students apply at the end of their junior year for admission to the linked programs.

Master of Science Degree Requirements

The Master of Science program requires completion of 8 three-credit courses and 6 thesis research credits. The five technical electives should be chosen to meet the student's research and career objectives.

BME Common Core (Choose Three)		9
BME 720	Modern Biomedical Instrumentation	
BME 721	Mathematical Modeling in Physiology	
BME 726	Biomaterials	
BME 792	Biomechanics	
BME Technical Electives (Choose Three)		9
BME 554	Introduction to Bioelectrics	
BME 562	Introduction to Medical Image Analysis	
BME 564	Biomedical Applications of Low Temperature Plasmas	
BME 612	Digital Signal Processing I	
BME 720	Modern Biomedical Instrumentation	
BME 721	Mathematical Modeling in Physiology	
BME 724	Neural Engineering	

BME 740	Regenerative Medicine	
BME 751	Computational and Statistical Methods in Biomedical Engineering	
BME 762	Applied Medical Image Analysis	
BME 783	Digital Image Processing	
BME 795	Special Topics in Biomedical Engineering	
Approved Technical Electives*		6
BME 699 Thesis		6
Total Hours		30

* The technical elective courses can be selected from the biomedical engineering technical electives or a wide variety of appropriate graduate courses in engineering, biology, chemistry, psychology, computer science, modeling and simulation, mathematics, statistics, or other programs. Technical electives without the BME prefix must be approved by the graduate program director.

Doctor of Philosophy, Engineering - Biomedical Engineering

Doctor of Philosophy Admission Requirements

Admission to the Ph.D. program in biomedical engineering is in accordance with Old Dominion University and Frank Batten College of Engineering and Technology requirements for doctoral programs as specified in this catalog. Specific additional requirements include the following:

1. Completion of a master's degree in a closely related field is expected. However, students who have completed 24 credits of graduate courses in an appropriate field from an accredited institution or have demonstrated an exceptionally high level of academic capability may petition for direct admittance into the program.
2. A minimum GPA of 3.50 (out of 4.0) is required of most students. A student with a lower GPA meeting ODU's graduate admission requirements and with evidence of a high level of professional capability may be eligible for admission to the program upon submission of a petition to the graduate program director.
3. Recent scores, typically, not more than five years old, on the Graduate Record Examination's (GRE) verbal, quantitative, and analytical writing sections must be submitted by all applicants.
4. Three letters of recommendation (typically at least two of which are from faculty in the highest degree program completed when the application is within five years of graduation from that degree program) are encouraged but not required.
5. The applicant must submit a resume and a statement of purpose and goals.
6. Foundation knowledge in physics, basic chemistry, physiology, computer programming, and mathematics (including differential equations and statistics) is expected. Some leveling courses may be required to complement the student's expertise, namely in physiology, statistics, and differential equations.
7. The Frank Batten College of Engineering and Technology at Old Dominion University has the Direct Bachelor-to-Ph.D. and linked Bachelor/Ph.D. programs that allow exceptionally well-qualified undergraduate students to apply for admission directly to a Ph.D. program. Typically, undergraduate students apply at the end of their junior year for admission to the linked programs.

Doctor of Philosophy Degree Requirements

The Ph.D. in biomedical engineering is offered in accordance with the general requirements for doctoral degrees as specified in the Requirements for Graduate Degree Section of this catalog. Specific program of study requirements include the following:

1. Completion of a minimum of 48 hours of graduate credits to include: a minimum of 24 credits of course work beyond the master's degree and

a minimum of 24 credits of dissertation research. At least 15 credits of non-dissertation course work must be at the 800-level. The Graduate Program Director in concurrence with the Chair can approve exceptions to these requirements under special circumstances.

2. Successful completion of a written diagnostic examination before the end of the first academic year.
3. Successful completion of a written and oral qualifying examination near the completion of the coursework.
4. Successful presentation of a dissertation research proposal at the beginning of the dissertation research.
5. The successful completion and public defense of a dissertation representing independent, original research worthy of publication in a peer-reviewed scholarly journal. At least one published and one submitted manuscript as first author in peer-reviewed, indexed journals are expected.

The program of study will be developed with the approval of the graduate program director and the student's advisor. The program shall include a common core of 14 credits and 10 credits of technical electives.

BME Common Core *	15
BME 820	Modern Biomedical Instrumentation
BME 821	Mathematical Modeling in Physiology
BME 826	Biomaterials
BME 892	Biomechanics
BME 847	Responsible Conduct of Research (2 CH)
BME 830	Predoctoral Fellowship Grant Writing (1 CH)
Technical Electives **	9
BME 554	Introduction to Bioelectrics
BME 562	Introduction to Medical Image Analysis
BME 564	Biomedical Applications of Low Temperature Plasmas
BME 612	Digital Signal Processing I
BME 824	Neural Engineering
BME 840	Regenerative Medicine
BME 851	Computational and Statistical Methods in Biomedical Engineering
BME 855	Biomembranes and Ion Channels
BME 862	Applied Medical Image Analysis
BME 883	Digital Image Processing
BME 895	Special Topics in Biomedical Engineering
Dissertation Research	24
BME 899	PHD Dissertation Research
Total Hours	48

* Students who have completed any of the core courses at the 700-level as part of a previous degree or program may substitute these courses with 800-level BME electives approved by the graduate program director.

** The technical elective courses provide a basis for dissertation research and future career objectives. These courses can be selected from the biomedical engineering technical electives or a wide variety of appropriate graduate courses in engineering, biology, chemistry, psychology, computer science, modeling and simulation, mathematics, statistics, or other programs. No more than six credits from course work satisfying foundation knowledge requirements may be included in the program of study for elective credit. At least 15 credits of non-dissertation course work must be at the 800-level. A minimum of 3 credits must be selected from the biomedical engineering technical electives list; the remaining credits can be selected from this list or other

graduate courses with approval of the student's advisor and the graduate program director.

Advanced Engineering Certificate - Biomedical Engineering

The Graduate Certificate in Biomedical Engineering Program offers students and professionals the opportunity to further their knowledge with advanced study in the growing area of Biomedical Engineering. The program is designed to provide well-rounded instruction in several key facets of Biomedical Engineering. Those who complete the Program receive the Advanced Engineering Certificate in Biomedical Engineering from Old Dominion University and a letter of recognition from the Batten College of Engineering and Technology. Courses taken for the certificate program may later be applied to the M.E. or Ph.D. degree in Biomedical Engineering. For complete information on the admission and certificate requirements, please refer to the Batten College of Engineering and Technology's section on graduate certificate programs at: /graduate/frankbattencollegeofengineeringandtechnology/#interdisciplinarygraduatecertificateprograms. (<http://catalog.odu.edu/graduate/frankbattencollegeofengineeringandtechnology/#interdisciplinarygraduatecertificateprograms>)

BIOMEDICAL ENGINEERING Courses

BME 503. Introduction to Mathematical Modeling in Physiology. 3 Credits.

This course introduces model development and model formulation with differential equations in physiology. Students will learn how to use Matlab to solve differential equations and visualize their results. The physiological focus will be on cellular physiology, particularly ion channel dynamics and homeostasis. Prerequisites: BIOL 240 or BIOL 250 and MATH 200 or MATH 205 or MATH 211.

BME 504. Introduction to Biomaterials. 3 Credits.

This course will introduce the properties of biomedical materials used as implants, prostheses, orthosis, and tissue-engineered materials as medical devices in contact with tissues and organs. Biocompatibility, immunological responses, wound healing, clotting cascade, surface compatibility and characterization of materials used for implantable medical devices will be introduced. Other topics such as ethical considerations and medical device regulatory mechanisms will be presented. Prerequisites: BIOL 240 or BIOL 250 and MATH 200 or MATH 205 or MATH 211.

BME 505. Biomechanics. 3 Credits.

The purpose of this course is to achieve a broad overview of biomechanics, focused on the musculoskeletal system. Students will explore multiscale mechanics, including whole-body movement and mechanical properties of the structures in the musculoskeletal system. Additionally, students will survey the experimental methods and computational modeling techniques used in biomechanics research. Prerequisites: MATH 212.

BME 509. Introduction to Regenerative Medicine. 3 Credits.

This course will introduce fundamental knowledge in regenerative medicine including therapeutic applications of biomaterials, tissue and stem cell engineering, gene therapy and bioelectrics, with emphasis on structure-function relationships of biologic systems. In addition to lecture, students will have opportunities for group discussions and presentations on milestone work related to tissue regeneration. Students will leave with a thorough understanding of true mammalian regeneration, wound healing/repair processes, and medical device milestones as related to human tissue regeneration and repair. Prerequisites: BIOL 240 or BIOL 250 and MATH 200 or MATH 205 or MATH 211.

BME 554. Introduction to Bioelectrics. 3 Credits.

This course covers the electrical properties of cells and tissues as well as the use of electrical and magnetic signals and stimuli in the diagnosis and treatment of disease. Typical topics to be covered include basic cell physiology, endogenous electric fields in the body, electrocardiography, cardiac pacing defibrillation, electrotherapy, electroporation, electrotherapy in wound healing. In addition ultra-short electrical pulses for intracellular manipulation and the application of plasmas to biological systems will be covered.

BME 562. Introduction to Medical Image Analysis. 3 Credits.

Introduction to basic concepts in medical image analysis. Medical image registration, segmentation, feature extraction, and classification are discussed. Basic psychophysics, fundamental ROC analysis and FROC methodologies are covered. Cross-listed with ECE 562/MSIM 562.

BME 564. Biomedical Applications of Low Temperature Plasmas. 3 Credits.

This course is cross listed with ECE and Biology. It is designed to be taken by senior undergraduate students and first year graduate students. The course contents are multidisciplinary, combining materials from engineering and the biological sciences. The course covers an introduction to the fundamentals of non-equilibrium plasmas, low temperature plasma sources, and cell biology. This is followed by a detailed discussion of the interaction of low temperature plasma with biological cells, both prokaryotes and eukaryotes. Potential applications in medicine such as wound healing, blood coagulation, sterilization, and the killing of various types of cancer cells will be covered. Prerequisites: Senior standing.

BME 612. Digital Signal Processing I. 3 Credits.

This course will present the fundamentals of digital signal processing. Topics will include frequency domain analysis of discrete-time linear systems, sampling and reconstruction of signals, the Discrete Fourier Transform (DFT) and Fast Fourier Transform (FFT), and digital filter design and implementations. Practical applications and examples will be discussed. Problem solving using MATLAB is required. Cross-listed with ECE 612. Prerequisite: ECE 381 or equivalent.

BME 695. Topics in Biomedical Engineering. 3 Credits.

This course will be offered as needed, depending upon the need to introduce special subjects to target specific areas of master's-level specializations in biomedical engineering.

BME 698. Master's Project. 1-3 Credits.

Individual project directed by the student's professor in major area of study.

BME 699. Master's Thesis. 1-9 Credits.

Directed research for the master's thesis. Prerequisite: departmental approval.

BME 720. Modern Biomedical Instrumentation. 3 Credits.

This course covers the design of modern biomedical instruments including select diagnostic, assistive, therapeutic, prosthetic, imaging, and virtual devices and systems. Techniques for mechanical, electrical, and chemical sensor and transducer design; stimulation and measurement; data acquisition; digital signal processing; and data visualization will be examined.

BME 721. Mathematical Modeling in Physiology. 3 Credits.

This course on mathematical modeling in human physiology emphasizes the development of mathematical models, their implementation, and the interpretation of simulation data. The course focuses on cellular physiology, including membrane channels, excitability, and calcium dynamics; it also covers intercellular communication and spatially distributed systems.

BME 724. Neural Engineering. 3 Credits.

This course presents engineering techniques for the restoration and augmentation of human function via direct interactions between the nervous system and artificial devices, with particular emphasis on brain-computer interfaces. Novel interfaces, hardware and computational issues, and practical and ethical considerations will also be covered.

BME 726. Biomaterials. 3 Credits.

This course cover fundamental principles and properties of biomedical materials used as implants, prostheses, orthosis, and tissue-engineered materials as medical devices in contact with tissues and organs. Advanced concepts of biocompatibility and material characterization will be discussed. Physiological response factors associated with materials and implanted devices used in the human body will be presented, including immunological responses, wound healing, clotting cascade and surface compatibility. Other topics such as ethical considerations and medical device regulatory mechanisms will be discussed.

BME 730. Predoctoral Fellowship Grant Writing. 1 Credit.

This course provides students important tools and experience in the vital grantsmanship area, which is needed to succeed in the competitive academic landscape. Students will be exposed to information regarding major predoctoral fellowships including NIH, NSF, DoD, and AHA, culminating in a grant proposal submission to the appropriate institution.

BME 740. Regenerative Medicine. 3 Credits.

This course covers a range of active research topics in regenerative medicine, including therapeutic applications of biomaterials, tissue and stem cell engineering, gene therapy and bioelectrics, with emphasis on structure-function relationships of biological systems. Upon completion of the course students should leave with a thorough understanding of biological systems structure-function relationships and associated biomimetic therapeutic approaches in regenerative medicine. Prerequisites: BIOL 240 or BIOL 250 and MATH 200 or MATH 205 or MATH 211.

BME 741. Principles of Visualization. 3 Credits.

Well-designed graphical media capitalizes on human facilities for processing visual information and thereby improves comprehension, memory, inference, and decision making. This course teaches techniques and algorithms for creating effective visualizations based on principles and techniques from graphic design, visual art, perceptual psychology and cognitive science. Both users and developers of visualization tools and systems will benefit from this course.

BME 747. Responsible Conduct of Research. 2 Credits.

The course will introduce students to the responsible conduct of science and scientific research.

BME 751. Computational and Statistical Methods in Biomedical Engineering. 3 Credits.

This course covers the theoretical foundation and application of commonly used techniques in biomedical engineering. Topics include linear algebra, partial differential equations, regression analysis, applied probabilities, multivariate distributions, Bayesian statistics, hypothesis tests, multiple comparisons, ANOVA, solution of non-linear equations, numerical methods and optimization. Programming software will be used to perform simulations and analyze biomedical data. Prerequisites: Graduate status.

BME 754. Advanced Bioelectrics. 3 Credits.

Bioelectrics is a new field encompassing both the science and technology of applying electrical stimuli to biological systems. This course covers the pulsed power technology that is required to generate electrical stimuli as well as the biological responses they evoke in cells and tissues. Particular emphasis is placed on the medical applications of bioelectrics, including tumor ablation, gene electrotransfer, wound healing, decontamination with cold plasma, and treatment of cardiac arrhythmias. Prerequisites: ECE 454 or ECE 554 or BIOE 454 or BIOE 554.

BME 755. Biomembranes and Ion Channels. 3 Credits.

This course will give an overview of the structure and dynamics of biomembranes, the ion channels that are embedded in them, and the electrical properties of biomembranes. Topics include molecular dynamics modeling of biomembranes, membrane damage and repair, ion channel dynamics and their experimental assessment using patch clamping, and excitability in neurons and cardiomyocytes. Prerequisite: ECE 454 or ECE 554 or BIOL 523.

BME 762. Applied Medical Image Analysis. 3 Credits.

Course explores hands-on exposure to state-of-the-art algorithms in medical image analysis, which builds on open-source software (Insight Segmentation and Registration Toolkit - ITK), as well as the principles of medical image acquisition in the modalities of clinical interest. Medical imaging modalities - X-rays, CT, and MRI/ITK image pipeline; image enhancement, feature detection; segmentation - basic techniques, feature-based classification and clustering, graph cuts, active contour and surface models; surface and volume meshing; registration - transformations, similarity criteria; shape and appearance models are all explored and discussed in this course. Prerequisites: Knowledge of C++ and object-oriented programming.

BME 783. Digital Image Processing. 3 Credits.

Principles and techniques of two-dimensional processing of images. Concepts of scale and spatial frequency. Image filtering in spatial and transform domains. Applications include image enhancement and restoration, image compressing, biomedical imaging for diagnosis of disease, and image segmentation for computer vision. Prerequisites: ECE 782 or ECE 882.

BME 792. Biomechanics. 3 Credits.

The purpose of this course is to achieve a broad overview of biomechanics, focused on the musculoskeletal system. Students will explore multiscale mechanics, including whole-body movement and mechanical properties of the structures in the musculoskeletal system. Additionally, students will survey the experimental methods and computational modeling techniques used in biomechanics research. Prerequisites: MATH 212 or equivalent.

BME 794. Cellular Biomechanics. 3 Credits.

A broad introduction to the field of cellular biomechanics. Topics include overview of cell architecture, cytoskeleton, adhesion and molecular motors, biomolecular/biopolymer dynamics and mechanics, techniques to measure cell mechanical properties, techniques to mechanically stimulate cells, models of cell mechanical behavior, mechanobiology and mechanotransduction. Will include discussion of classic and current research articles. Course content will aim to cater to students with diverse backgrounds – students with biological science background will be exposed to physical science concepts and analysis; students with engineering/physical science background will be exposed to biological phenomena and concepts. Pre- or corequisite: MATH 212.

BME 795. Special Topics in Biomedical Engineering. 1-3 Credits.

Special courses covering selected graduate-level topics in biomedical engineering.

BME 797. Independent Study. 1-3 Credits.

This course allows students to develop specialized expertise by independent study (supervised by a faculty member). Prerequisites: departmental approval.

BME 820. Modern Biomedical Instrumentation. 3 Credits.

This course covers the design of modern biomedical instruments including select diagnostic, assistive, therapeutic, prosthetic, imaging, and virtual devices and systems. Techniques for mechanical, electrical, and chemical sensor and transducer design; stimulation and measurement; data acquisition; digital signal processing; and data visualization will be examined.

BME 821. Mathematical Modeling in Physiology. 3 Credits.

This course on mathematical modeling in human physiology emphasizes the development of mathematical models, their implementation, and the interpretation of simulation data. The course focuses on cellular physiology, including membrane channels, excitability, and calcium dynamics; it also covers intercellular communication and spatially distributed systems.

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BME 826. Biomaterials. 3 Credits.

This course cover fundamental principles and properties of biomedical materials used as implants, prostheses, orthosis, and tissue-engineered materials as medical devices in contact with tissues and organs. Advanced concepts of biocompatibility and material characterization will be discussed. Physiological response factors associated with materials and implanted devices used in the human body will be presented, including immunological responses, wound healing, clotting cascade and surface compatibility. Other topics such as ethical considerations and medical device regulatory mechanisms will be discussed.

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BME 841. Principles of Visualization. 3 Credits.

Well-designed graphical media capitalizes on human facilities for processing visual information and thereby improves comprehension, memory, inference, and decision making. This course teaches techniques and algorithms for creating effective visualizations based on principles and techniques from graphic design, visual art, perceptual psychology and cognitive science. Both users and developers of visualization tools and systems will benefit from this course.

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The course will introduce students to the responsible conduct of science and scientific research.

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This course covers the theoretical foundation and application of commonly used techniques in biomedical engineering. Topics include linear algebra, partial differential equations, regression analysis, applied probabilities, multivariate distributions, Bayesian statistics, hypothesis tests, multiple comparisons, ANOVA, solution of non-linear equations, numerical methods and optimization. Programming software will be used to perform simulations and analyze biomedical data. Prerequisites: Graduate status.

BME 854. Advanced Bioelectronics. 3 Credits.

Bioelectronics is a new field encompassing both the science and technology of applying electrical stimuli to biological systems. This course covers the pulsed power technology that is required to generate electrical stimuli as well as the biological responses they evoke in cells and tissues. Particular emphasis is placed on the medical applications of bioelectronics, including tumor ablation, gene electrotransfer, wound healing, decontamination with cold plasma, and treatment of cardiac arrhythmias. Prerequisites: ECE 454 or ECE 554 or BIOE 454 or BIOE 554.

BME 855. Biomembranes and Ion Channels. 3 Credits.

This course will give an overview of the structure and dynamics of biomembranes, the ion channels that are embedded in them, and the electrical properties of biomembranes. Topics include molecular dynamics modeling of biomembranes, membrane damage and repair, ion channel dynamics and their experimental assessment using patch clamping, and excitability in neurons and cardiomyocytes. Prerequisite: ECE 454 or ECE 554 or BIOL 523.

BME 862. Applied Medical Image Analysis. 3 Credits.

Course explores hands-on exposure to state-of-the-art algorithms in medical image analysis, which builds on open-source software (Insight Segmentation and Registration Toolkit - ITK), as well as the principles of medical image acquisition in the modalities of clinical interest. Medical imaging modalities - X-rays, CT, and MRI/ITK image pipeline; image enhancement, feature detection; segmentation - basic techniques, feature-based classification and clustering, graph cuts, active contour and surface models; surface and volume meshing; registration - transformations, similarity criteria; shape and appearance models are all explored and discussed in this course. Prerequisites: Knowledge of C++ and object-oriented programming.

BME 883. Digital Image Processing. 3 Credits.

Principles and techniques of two-dimensional processing of images. Concepts of scale and spatial frequency. Image filtering in spatial and transform domains. Applications include image enhancement and restoration, image compressing, biomedical imaging for diagnosis of disease, and image segmentation for computer vision. Prerequisites: ECE 783 and ECE 883.

BME 892. Biomechanics. 3 Credits.

The purpose of this course is to achieve a broad overview of biomechanics, focused on the musculoskeletal system. Students will explore multiscale mechanics, including whole-body movement and mechanical properties of the structures in the musculoskeletal system. Additionally, students will survey the experimental methods and computational modeling techniques used in biomechanics research. Prerequisites: MATH 212 or equivalent.

BME 894. Cellular Biomechanics. 3 Credits.

A broad introduction to the field of cellular biomechanics. Topics include overview of cell architecture, cytoskeleton, adhesion and molecular motors, biomolecular/biopolymer dynamics and mechanics, techniques to measure cell mechanical properties, techniques to mechanically stimulate cells, models of cell mechanical behavior, mechanobiology and mechanotransduction. Will include discussion of classic and current research articles. Course content will aim to cater to students with diverse backgrounds – students with biological science background will be exposed to physical science concepts and analysis; students with engineering/physical science background will be exposed to biological phenomena and concepts. Pre- or corequisite: MATH 212.

BME 895. Special Topics in Biomedical Engineering. 1-3 Credits.

Special courses covering selected graduate-level topics in biomedical engineering.

BME 897. Independent Study. 1-3 Credits.

This course allows students to develop specialized expertise by independent study (supervised by a faculty member). Prerequisites: departmental approval.

BME 899. PHD Dissertation Research. 1-9 Credits.

Directed research for the doctoral dissertation.

BME 999. Doctoral Graduate Credit. 1 Credit.

This course is a pass/fail course doctoral students may take to maintain active status after successfully passing the candidacy examination. All doctoral students are required to be registered for at least one graduate credit hour every semester until their graduation.

ELECTRICAL AND COMPUTER ENGINEERING Courses

ECE 503. Power Electronics. 3 Credits.

Power electronics provides the needed interface between an electrical source and an electrical load and facilitates the transfer of power from a source to a load by converting voltages and currents from one form to another. Topics include: alternating voltage rectification, Pulse Width Modulation (PWM), DC converters (Buck, Boost, Buck-Boost, Cuk and SEPIC converters), negative feedback control in power electronics, isolated switching mode power supply, flyback and forward power supply, solid state power switches, AC inverter. (Offered spring) Prerequisites: ECE 303, ECE 313 and a grade of C or better in ECE 202 and ECE 287.

ECE 504. Electric Drives. 3 Credits.

Electric drives efficiently control the torque, speed and position of electric motors. This course has a multi-disciplinary nature and includes fields such as electric machine theory, power electronics, and control theory. Topics include: switch-mode power electronics, magnetic circuit, DC motor, AC motor, Brushless DC motor, induction motor, speed control of induction motor, vector control of induction motor, stepper-motor. (offered fall) Prerequisites: ECE 303 and a grade of C or better in ECE 202 and ECE 287.

ECE 505. Power System Design & Analysis. 3 Credits.

This course covers basic power circuit analysis and introductory power system engineering and focuses on the transmission line design, power flow study, short circuit protection, and power distribution in electric power systems, followed by a survey of several applications and case studies. (offered fall) Prerequisites: ECE 303 or equivalent knowledge in electric machines and circuits.

ECE 506. Computer Graphics and Visualization. 3 Credits.

The course provides a practical treatment of computer graphics and visualization with emphasis on modeling and simulation applications. It covers digital image and signal processing basics such as sampling and discrete Fourier transform, computer graphics fundamentals, visualization principles, and software architecture for visualization in modeling and simulation. Written communication and information literacy skills are stressed in this course. (Cross listed with MSIM 541.) (Offered fall) Prerequisites: ECE 348 or CS 361.

ECE 507. Introduction to Game Development. 3 Credits.

An introductory course focused on game development theory and modern practices with emphasis on educational game development. Topics include game architecture, computer graphics theory, user interaction, audio, high level shading language, animation, physics, and artificial intelligence. The developed games can run on a variety of computer, mobile, and gaming platforms. (Cross listed with MSIM 508.) (Offered spring) Prerequisites: CS 361 or MSIM 331.

ECE 508. Fundamentals of Electric Vehicles. 3 Credits.

This course covers the fundamentals of electric vehicles and focuses on the components, power control, energy management, power train dynamics and other related topics in purely electric and hybrid electric vehicle systems, including a survey of several applications and case studies. (Offered spring) Prerequisites: ECE 303 and a grade of C or better in ECE 202 and ECE 287.

ECE 509. Introduction to Distributed Simulation. 3 Credits.

An introduction to distributed simulation. Topics include motivation for using distributed simulation, distributed simulation architectures, time management issues, and distributed simulation approaches. Current standards for distributed simulation are presented. Prerequisites: MSIM 331 or ECE 348.

ECE 510. Model Engineering. 3 Credits.

The goal of this course is to develop understanding of the various modeling paradigms appropriate for capturing system behavior and conducting digital computer simulation of many types of systems. The techniques and concepts discussed typically include UML, concept graphs, Bayesian nets, Markov models, Petri nets, system dynamics, Bond graphs, etc. Students will report on a particular technique and team to implement a chosen system model. (Cross-listed with MSIM 510.) (Offered spring) Prerequisites: MSIM 205 or equivalent. Pre- or corequisite: MSIM 320 or equivalent.

ECE 516. Cyber Defense Fundamentals. 3 Credits.

This course focuses on cybersecurity theory, information protection and assurance, and computer systems and networks security. The objectives are to understand the basic security models and concepts, learn fundamental knowledge and tools for building, analyzing, and attacking modern security systems, and gain hands-on experience in cryptographic algorithms, security fundamental principles, and Internet security protocol and standards. (Offered fall) Prerequisites: Permission of the instructor. Pre- or corequisite: ECE 355.

ECE 519. Cyber Physical System Security. 3 Credits.

Cyber Physical Systems (CPS) integrate computing, networking, and physical processes. The objectives of this course are to learn the basic concepts, technologies and applications of CPS, understand the fundamental CPS security challenges and national security impact, and gain hands-on experience in CPS infrastructures, critical vulnerabilities, and practical countermeasures. (Offered spring) Prerequisites: ECE 355 or permission of the instructor.

ECE 541. Advanced Digital Design and Field Programmable Gate Arrays. 3 Credits.

Course will present FPGA technologies and methods using CAD design tools for implementation of digital systems using FPGAs. Topics include advanced methods of digital circuit design including specification, synthesis, implementation and prototyping; managing multiple clock domains, static timing analysis, timing closure, system reset design, simulation, and optimization; troubleshooting using embedded logic analyzers and integrated development environments (IDEs). Practical system design examples include general purpose data processing, system on a chip (SOC) prototyping, hardware accelerators, and an introduction to domain specific architectures. (Offered spring) Prerequisites: ECE 341.

ECE 543. Computer Architecture. 3 Credits.

An introduction to computer architectures. Analysis and design of computer subsystems including central processing units, memories and input/output subsystems. Important concepts include datapaths, computer arithmetic, instruction cycles, pipelining, virtual and cache memories, direct memory access and controller design. (offered fall) Prerequisites: ECE 341 and ECE 346.

ECE 545. Introduction to Computer Vision. 3 Credits.

Overview of digital image processing including visual perception, image formation, spatial transformations, image enhancement, color image representation and processing, edge detection, image segmentation, and data processing method for computer vision applications. Hand-on projects will be introduced to better understand computer vision applications. (Offered fall) Prerequisites: A grade of C or better in ENGN 150 or CS 150. Pre- or corequisite: ECE 350.

ECE 550. Introduction to Machine Learning for Data Analytics Engineering. 3 Credits.

Machine Learning provides a practical treatment of design, analysis and implementation of algorithms, which learn from examples. Topics include multiple machine learning models: linear regression, logistic regression, neural networks, support vector machines, deep learning, Bayesian learning and unsupervised learning. Students are expected to use popular machine learning tools and algorithms to solve real data engineering problems. (Offered spring) Prerequisites: A grade of C or better in ENGN 150 or CS 150. Pre- or corequisite: ECE 350.

ECE 551. Communication Systems. 3 Credits.

Fundamentals of communication systems engineering. Modulation methods including continuous waveform modulation (amplitude, angle). Design and analysis of modulation systems and the performance in the presence of noise. Communication simulation exercises through computer experiments. (Offered spring) Prerequisites: ECE 304 and ECE 302.

ECE 552. Introduction to Wireless Communication Networks. 3 Credits.

Introduction to current wireless network technologies and standards. The radio frequency spectrum and radio wave propagation models (pathloss, fading, and multipath). The radio link and link budgets. Modulation, diversity, and multiple access techniques. Wireless network planning and operation. Current and emerging wireless technologies (satellite systems, vehicular/sensor networks). (Offered fall) Prerequisites: ECE 304 and ECE 302.

ECE 553. Analysis for Modeling and Simulation. 3 Credits.

An introduction to analysis techniques appropriate to the conduct of modeling and simulation studies. Topics include input modeling, random number generation, output analysis, variance reduction techniques, and experimental design. In addition, techniques for verification & validation are introduced. Course concepts are applied to real systems and data. Prerequisites: MSIM 205 or ECE 306 and ECE 304.

ECE 554. Introduction to Bioelectrics. 3 Credits.

Covers the electrical properties of cells and tissues as well as the use of electrical and magnetic signals and stimuli in the diagnosis and treatment of disease. Typical topics to be covered include basic cell physiology, endogenous electric fields in the body, electrocardiography, cardiac pacing, defibrillation, electrotherapy, electroporation, electrotherapy in wound healing. In addition, ultrashort electrical pulses for intracellular manipulation and the application of plasmas to biological systems will be covered. (Offered fall) Prerequisites: PHYS 111N or higher; MATH 200 or higher.

ECE 555. Network Engineering and Design. 3 Credits.

Emphasis is on gaining an understanding of networking design principles that entails all aspects of the network development life cycle. Topics include campus LAN models and design, VLANs, internetworking principles and design, WAN design, design of hybrid IP networks, differentiated vs. integrated services, traffic flow measurement and management. (offered spring) Prerequisites: ECE 355 or permission of the instructor.

ECE 558. Instrumentation. 3 Credits.

Computer interfacing using a graphical programming language with applications involving digital-to-analog conversion (DAC), analog-to-digital conversion (ADC), digital input output (DIO), Virtual Instrument System Architecture (VISA) and universal Service Bus (USB). Analysis of sampled data involving use of probability density function, mean and standard derivations, correlations, and the power spectrum. (offered spring, summer) Prerequisite: ECE 302 or permission of the instructor.

ECE 561. Automatic Control Systems. 3 Credits.

Analysis and design of control systems as found in automobiles and aircraft, autonomous vehicles, robots, and many other engineering systems. Time and frequency domain techniques such as root locus, Bode, Nyquist and state space techniques are utilized together with computer-aided analysis and design. (Offered fall) Prerequisites: ECE 302.

ECE 562. Introduction to Medical Image Analysis (MIA). 3 Credits.

Introduction to basic concepts in medical image analysis. Medical image registration, segmentation, feature extraction, and classification are discussed. Basic psychophysics, fundamental ROC analysis and FROC methodologies are covered. (Offered every other spring) Prerequisites: a grade of C or better in MATH 212.

ECE 563. Design and Modeling of Autonomous Robotic Systems. 3 Credits.

This course focuses on autonomous robotics systems with emphasis on using modeling and simulation (M&S) for system level design and testing. Fundamental concepts associated with autonomous robotic systems are discussed. Course topics include: robotic control, architectures, and sensors as well as more advanced concepts such as error propagation, localization, mapping and autonomy. Design strategies that leverage M&S to accelerate the development and testing of sophisticated autonomous robotic algorithms for individual or teams of robots are covered. Prerequisites: CS 150 or ENGN 150.

ECE 564. Biomedical Applications of Low Temperature Plasmas. 3 Credits.

This course is cross listed between ECE, BME and BIOL. It is designed to be taken by senior undergraduate students and first year graduate students. The course contents are multidisciplinary, combining materials from engineering and the biological sciences. The course covers an introduction to the fundamentals of non-equilibrium plasmas, low temperature plasma sources, and cell biology. This is followed by a detailed discussion of the interaction of low temperature plasma with biological cells, both prokaryotes and eukaryotes. Potential applications in medicine such as wound healing, blood coagulation, sterilization, and the killing of various types of cancer cells will be covered. (Offered fall) Prerequisites: Senior standing.

ECE 570. Foundations of Cyber Security. 3 Credits.

Course provides an overview of theory, tools and practice of cyber security and information assurance through prevention, detection and modeling of cyber attacks and recovery from such attacks. Techniques for security modeling, attack modeling, risk analysis and cost-benefit analysis are described to manage the security of cyber systems. Fundamental principles of cyber security and their applications for protecting software and information assets of individual computers and large networked systems are explored. Anatomy of some sample attacks designed to compromise confidentiality, integrity and availability of cyber systems are discussed. Cross-listed with MSIM 570. (Offered fall) Prerequisites: A grade of C or better in ENGN 150 or CS 150 and junior standing or permission of the instructor.

ECE 571. Introduction to Solar Cells. 3 Credits.

This course is designed to provide the fundamental physics and characteristics of photovoltaic materials and devices. A focus is placed on i) optical interaction, absorption, and design for photovoltaic materials and systems, ii) subsequent energy conversion processes in inorganic/organic semiconductor such as generation, recombination, and charge transport, and iii) photovoltaic testing and measurement techniques to characterize solar cells including contact and series resistance, open circuit voltage, short circuit current density, fill factor, and energy conversion efficiency of photovoltaic devices. (Offered fall) Prerequisites: ECE 332.

ECE 572. Plasma Processing at the Nanoscale. 3 Credits.

The science and design of partially ionized plasma and plasma processing devices used in applications such as etching and deposition at the nanoscale. Gas phase collisions, transport parameters, DC and RF glow discharges, the plasma sheath, sputtering, etching, and plasma deposition. (Offered fall) Prerequisites: ECE 323.

ECE 573. Solid State Electronics. 3 Credits.

The objective of this course is to understand basic semiconductor devices by understanding semiconductor physics (energy bands, carrier statistics, recombination and carrier drift and diffusion) and to gain an advanced understanding of the physics and fundamental operation of advanced semiconductor devices. Following the initial introductory chapters on semiconductor physics, this course will focus on the theory of p-n junctions, metal-semiconductor Schottky diodes, MOS capacitors, MOS field effect transistors (MOSFET) and bipolar junction transistors (BJTs). (Offered fall) Prerequisites: ECE 313, ECE 323, ECE 332 and MATH 212.

ECE 574. Optical Fiber Communications. 3 Credits.

This course introduces seniors and first year graduates to the physics and design of optical fiber communication systems. The topics covered are: electromagnetic waves; optical sources including laser diodes; optical amplifiers; modulators; optical fibers; attenuation and dispersion in optical fibers; photodetectors; optical receivers; noise considerations in optical receivers; optical communication systems. (Offered spring) Prerequisites: ECE 323.

ECE 575. Transportation Data Analytics. 3 Credits.

This course presents the basic techniques for transportation data analytics. It will discuss statistical modeling, prominent algorithms, and visualization approaches to analyze both small- and large-scale data sets generated from transportation systems. Practices of using different data for various real-world traffic/transportation applications and decision making will also be discussed. Prerequisites: Basic probability and statistics (e.g., STAT 330 or ECE 304); any programming language such as C, Python or Java is beneficial but not required.

ECE 583. Embedded Systems. 3 Credits.

This course covers fundamentals of embedded systems: basic architecture, programming, and design. Topics include processors and hardware for embedded systems, embedded programming and real time operating systems. (Offered fall) Pre- or corequisite: ECE 346.

ECE 595. Topics in Electrical and Computer Engineering. 1-3 Credits.

Study of topics in electrical and computer engineering. Prerequisites: departmental approval.

ECE 596. Topics in Electrical and Computer Engineering. 1-3 Credits.

Study of topics in electrical and computer engineering. Prerequisites: departmental approval.

ECE 601. Linear Systems. 3 Credits.

A comprehensive introduction to the analysis of linear dynamical systems from an input-output and state space point of view. Concepts from linear algebra, numerical linear algebra and linear operator theory are used throughout. Some elements of state feedback design and state estimation are also covered. Prerequisites: MATH 307.

ECE 607. Machine Learning I. 3 Credits.

Course provides a practical treatment of design, analysis, implementation and applications of algorithms. Topics include multiple machine learning models: linear models, neural networks, support vector machines, instance-based learning, Bayesian learning, genetic algorithms, ensemble learning, reinforcement learning, unsupervised learning, etc. Prerequisites: Graduate standing.

ECE 611. Numerical Methods in Engineering Analysis. 3 Credits.

Course intended to provide graduate students in Electrical and Computer Engineering with a basic knowledge of numerical methods applied to engineering problem-solving process. The course includes the following topics: Introduction to computing (Matlab), Truncation errors and Taylor series, Numerical integration, Solution of non-linear equations, Least-Square regression, Interpolations, Ordinary and partial differential equations, and Finite difference methods. Applications to the area of electrical engineering. Prerequisites: Graduate standing or advisor's permission (for BS/MS students).

ECE 612. Digital Signal Processing I. 3 Credits.

This course will present the fundamentals of digital signal processing. Topics will include frequency domain analysis of discrete-time linear systems, sampling and reconstruction of signals, the Discrete Fourier Transform (DFT) and Fast Fourier Transform (FFT), and digital filter design and implementations. Practical applications and examples will be discussed. Problem solving using MATLAB is required. Prerequisites: ECE 381 or equivalent.

ECE 623. Electromagnetism. 3 Credits.

Review of electrostatic and magnetostatic concepts, time varying field, Maxwell's equations, plane wave propagation in various media, transmission lines, optical wave guides, resonant cavities, simple radiation systems, and their engineering applications. Prerequisites: ECE 323 or equivalent.

ECE 642. Computer Networking. 3 Credits.

The course is based on the ISO (International Standard Organization) OSI (Open Systems Interconnection) reference model for computer networks. A focus is placed on the analysis of protocols at different layers, network architectures, and networking systems performance analysis. Current topic areas include LANs, MANs, TCP/IP networks, mobile communications, and ATM. Prerequisites: ECE 455 or ECE 555 or permission of the instructor.

ECE 643. Computer Architecture Design. 3 Credits.

Digital computer design principles. The course focuses on design of state-of-the-art computing systems. An emphasis is placed on superscalar architectures focusing on the pipelining and out-of-order instruction execution operations. Prerequisites: ECE 443 or ECE 543.

ECE 648. Advanced Digital Design. 3 Credits.

This course introduces methods for using high level hardware description language such as VHDL and/or Verilog for the design of digital architecture. Topics include top-down design approaches, virtual prototyping, design abstractions, hardware modeling techniques, algorithmic and register level design, synthesis methods, and application decomposition issues. Final design project is required. Prerequisites: ECE 341.

ECE 651. Statistical Analysis and Simulation. 3 Credits.

An introduction to probabilistic and statistical techniques for analysis of signals and systems. This includes a review of probability spaces, random variables, and random processes. Analysis and simulation of systems with random parameters and stochastic inputs are considered. Prerequisites: MATH 312 and one undergraduate course in probability or statistics or permission of instructor.

ECE 652. Wireless Communications Networks. 3 Credits.

Fundamental concepts in wireless communication systems and networks: radio waveform propagation modeling (free-space, reflections and multipath, fading, diffraction and Doppler effects); physical and statistical models for wireless channels; modulation schemes for wireless communications and bandwidth considerations; diversity techniques; MIMO systems and space-time coding; multiuser systems and multiple access techniques (TDMA, FDMA, CDMA); spread spectrum and multiuser detection; introduction to wireless networking and wireless standards; current and emerging wireless technologies. Prerequisites: ECE 451 or ECE 551 or permission of instructor.

ECE 667. Cooperative Education. 1-3 Credits.

Student participation for credit based on academic relevance of the work experience, criteria, and evaluative procedures as formally determined by the department and the Cooperative Education/Career Development Services program prior to the semester in which the work experience is to take place.

ECE 668. Internship. 1-3 Credits.

Academic requirements will be established by the department and will vary with the amount of credit desired. Allows students an opportunity to gain short duration career related experience. Meant to be used for one-time experience. Work may or may not be paid. Project is completed during the term. Prerequisites: approval by department and Career Development Services.

ECE 669. Practicum. 1-3 Credits.

Academic requirements will be established by the department and will vary with the amount of credit desired. Allows students an opportunity to gain short duration career related experience. Student is usually already employed - this is an additional project in the organization. Prerequisites: approval by department and Career Development Services.

ECE 695. Topics in Electrical or Computer Engineering. 3 Credits.

This course will be offered as needed, depending upon the need to introduce special subjects to target specific areas of master's-level specializations in electrical or computer engineering.

ECE 698. Master's Project. 1-3 Credits.

Individual project directed by the student's professor in major area of study.

ECE 699. Thesis. 1-9 Credits.

Directed research for the master's thesis. Prerequisites: departmental approval.

ECE 731. Graduate Seminar. 1 Credit.

Graduate seminar presentations concerning technical topics of current interest given by faculty and invited speakers. Prerequisites: graduate standing.

ECE 742. Computer Communication Networks. 3 Credits.

This is an advanced level course in data communications. A focus is placed on the analysis, modeling, and control of computer communication systems. Topics include packet switched networks, circuit switched networks, ATM networks, network programming, network control and performance analysis, network security, and wireless sensor networks. Prerequisites: ECE 642 or permission of instructor.

ECE 751. Computational and Statistical Methods in Biomedical Engineering. 3 Credits.

This course covers the theoretical foundation and application of commonly used techniques in biomedical engineering. Topics include linear algebra, partial differential equations, regression analysis, applied probabilities, multivariate distributions, Bayesian statistics, hypothesis tests, multiple comparisons, ANOVA, solution of non-linear equations, numerical methods and optimization. Programming software will be used to perform simulations and analyze biomedical data.

ECE 754. Advanced Bioelectrics. 3 Credits.

Bioelectrics is a new field encompassing both the science and technology of applying electrical stimuli to biological systems. This course covers the pulsed power technology that is required to generate electrical stimuli as well as the biological responses they evoke in cells and tissues. Particular emphasis is placed on the medical applications of bioelectrics, including tumor ablation, gene electrotransfer, wound healing, decontamination with cold plasma, and treatment of cardiac arrhythmias. Prerequisite: ECE 454 or ECE 554 or BIOE 454 or BIOE 554.

ECE 755. Biomembranes and Ion Channels. 3 Credits.

This course will give an overview of the structure and dynamics of biomembranes, the ion channels that are embedded in them, and the electrical properties of biomembranes. Topics include molecular dynamics modeling of biomembranes, membrane damage and repair, ion channel dynamics and their experimental assessment using patch clamping, and excitability in neurons and cardiomyocytes. Prerequisites: ECE 454 or ECE 554 or BIOL 523.

ECE 762. Digital Control Systems. 3 Credits.

Mathematical representation, analysis, and design of discrete-time and sampled-data control systems. Topics include transfer function and state space representations, stability, the root locus method, frequency response methods, and state feedback. Prerequisites: ECE 381, ECE 461 or ECE 561, and ECE 601 or permission of instructor.

ECE 763. Multivariable Control Systems. 3 Credits.

A comprehensive introduction to techniques applicable in control of complex systems with multiple inputs and outputs. Both the frequency domain and state variable approaches are utilized. Special topics include robust and optimal control. Prerequisites: ECE 461 or ECE 561 and ECE 601 or permission of instructor.

ECE 766. Nonlinear Control Systems. 3 Credits.

An introduction to mathematical representation, analysis, and design of nonlinear control systems. Topics include phase-plane analysis, Lyapunov stability theory for autonomous and nonautonomous systems, formal power series methods and differential geometric design techniques. Prerequisites: ECE 461 or ECE 561 and ECE 601 or permission of instructor.

ECE 772. Fundamentals of Solar Cells. 3 Credits.

The course provides an overview of the fundamentals of solar cell technologies, design, and operation. The course is designed for graduate students in Engineering and Science interested in the field of alternative energy. The course objectives are to make sure each student: understands the various forms of alternative energies, understands solar cell design, understands solar cell operation, and acquires knowledge of the various solar cells technologies. The topics to be covered include: Alternative energies; Worldwide status of Photovoltaics; Solar irradiance; Review of semiconductor properties; Generation, recombination; Basic equations of device physics; p-n junction diodes; Ideal solar cells; Efficiency limits; Efficiency losses and measurements; Module fabrication; c-Si technology; classical; Photovoltaic systems; Design of stand-alone system; Residential PV systems. Prerequisites: Graduate standing in Engineering and Science.

ECE 773. Introduction to Nanotechnologies. 3 Credits.

This course will introduce the rapidly emerging field of nanotechnology with special focus on underlying principles and applications relevant to the nanoscale dimensions. Specifically, this course will cover (1) the basic principles related to synthesis and fabrication of nanomaterials and nanostructures, (2) zero-, one-, two- and three-dimensional nanostructures, (3) characterization and properties of nanomaterials, and (4) application of nanoscale devices. Prerequisites: graduate standing in Engineering and Science.

ECE 774. Semiconductor Characterization. 3 Credits.

Introduction of basic methods for semiconductor material and device characterization. Topics include resistivity, carrier doping concentration, contact resistance, Schottky barrier height, series resistance, channel length, threshold voltage, mobility, oxide and interface trapped charge, deep level impurities, carrier lifetime, and optical, chemical and physical characterization. Prerequisites: ECE 473 or ECE 573 or equivalent.

ECE 775. Non-thermal Plasma Engineering. 3 Credits.

This course covers the fundamental principals governing low temperature plasma discharges and their applications. First the fundamental properties of plasmas are introduced. These include the kinetic theory of gases, collisional processes, and plasma sheaths. Then in-depth coverage of the physical mechanisms underlying the operation of non-equilibrium plasma discharges is presented, including important characteristics such as their ignition, evolution, and eventual quenching. Finally, practical applications of non-thermal plasmas, including applications in biology and medicine, are presented. Prerequisites: graduate standing.

ECE 777. Semiconductor Process Technology. 3 Credits.

Theory, design and fabrication of modern integrated circuits that consist of nano scale devices and materials. Topics include crystal growth and wafer preparation process including epitaxy, thin film deposition, oxidation, diffusion, ion implantation, lithography, dry etching, VLSI process integration, diagnostic assembly and packaging, yield and reliability. Prerequisites: ECE 473 or ECE 573.

ECE 780. Machine Learning II. 3 Credits.

Advanced topics in machine learning and pattern recognition systems. Data reduction techniques including principle component analysis, independent component analysis and manifold learning. Introduction to sparse coding and deep learning for data representation and feature extraction. Prerequisite: ECE 607 or equivalent.

ECE 782. Digital Signal Processing II. 3 Credits.

Review of time domain and frequency domain analysis of discrete time signals and systems. Fast Fourier Transforms, recursive and non-recursive digital filter analysis and design, multirate signal processing, optimal linear filters, and power spectral estimation. Prerequisites: ECE 612 or equivalent.

ECE 783. Digital Image Processing. 3 Credits.

Principles and techniques of two-dimensional processing of images. Concepts of scale and spatial frequency. Image filtering in spatial and transform domains. Applications include image enhancement and restoration, image compressing, and image segmentation for computer vision. Prerequisites: ECE 381 or ECE 612 or ECE 782 or ECE 882.

ECE 784. Computer Vision. 3 Credits.

Principles and applications of computer vision, advanced image processing techniques as applied to computer vision problems, shape analysis and object recognition. Prerequisite: graduate standing.

ECE 787. Digital Communications. 3 Credits.

Fundamental concepts of digital communication and information transmission: information sources and source coding; orthonormal expansions of signals, basis functions, and signal space concepts; digital modulation techniques including PAM, QAM, PSK and FSK; matched filters, demodulation and optimal detection of symbols and sequences; bandwidth; mathematical modeling of communication channels; channel capacity. Prerequisites: ECE 451/ECE 551 or equivalent or permission of the instructor.

ECE 795. Topics in Electrical and Computer Engineering. 3 Credits.

Topics in Electrical and Computer Engineering Prerequisites: departmental approval.

ECE 796. Topics in Electrical and Computer Engineering. 3 Credits.

Study of selected topics in Electrical and Computer Engineering. Prerequisites: departmental approval.

ECE 797. Independent Study. 1-3 Credits.

This course allows students to develop specialized expertise by independent study (supervised by a faculty member). Prerequisites: departmental approval.

ECE 831. Graduate Seminar. 1 Credit.

Graduate seminar presentations concerning technical topics of current interest given by faculty and invited speakers.

ECE 842. Computer Communication Networks. 3 Credits.

This is an advanced level course in data communications. A focus is placed on the analysis, modeling, and control of computer communication systems. Topics include packet switched networks, circuit switched networks, ATM networks, network programming, network control and performance analysis, network security, and wireless sensor networks. Prerequisites: ECE 642 or permission of instructor.

ECE 851. Computational and Statistical Methods in Biomedical Engineering. 3 Credits.

This course covers the theoretical foundation and application of commonly used techniques in biomedical engineering. Topics include linear algebra, partial differential equations, regression analysis, applied probabilities, multivariate distributions, Bayesian statistics, hypothesis tests, multiple comparisons, ANOVA, solution of non-linear equations, numerical methods and optimization. Programming software will be used to perform simulations and analyze biomedical data.

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Bioelectrics is a new field encompassing both the science and technology of applying electrical stimuli to biological systems. This course covers the pulsed power technology that is required to generate electrical stimuli as well as the biological responses they evoke in cells and tissues. Particular emphasis is placed on the medical applications of bioelectrics, including tumor ablation, gene electrotransfer, wound healing, decontamination with cold plasma, and treatment of cardiac arrhythmias. Prerequisite: ECE 454 or ECE 554 or BIOE 454 and BIOE 554.

ECE 855. Biomembranes and Ion Channels. 3 Credits.

This course will give an overview of the structure and dynamics of biomembranes, the ion channels that are embedded in them, and the electrical properties of biomembranes. Topics include molecular dynamics modeling of biomembranes, membrane damage and repair, ion channel dynamics and their experimental assessment using patch clamping, and excitability in neurons and cardiomyocytes. Prerequisite: ECE 454 or ECE 554 or BIOL 523.

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Mathematical representation, analysis, and design of discrete-time and sampled-data control systems. Topics include transfer function and state space representations, stability, the root locus method, frequency response methods, and state feedback. Prerequisites: ECE 381, ECE 461 or ECE 561, and ECE 601 or permission of instructor.

ECE 863. Multivariable Control Systems. 3 Credits.

A comprehensive introduction to techniques applicable in control of complex systems with multiple inputs and outputs. Both the frequency domain and state variable approaches are utilized. Special topics include robust and optimal control. Prerequisites: ECE 461 or ECE 561 and ECE 601 or permission of the instructor.

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An introduction to mathematical representation, analysis, and design of nonlinear control systems. Topics include phase-plane analysis, Lyapunov stability theory for autonomous and nonautonomous systems, formal power series methods and differential geometric design techniques. Prerequisites: ECE 461 or ECE 561 and ECE 601 or permission of instructor.

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This course will introduce the rapidly emerging field of nanotechnology with special focus on underlying principles and applications relevant to the nanoscale dimensions. Specifically, this course will cover (1) the basic principles related to synthesis and fabrication of nanomaterials and nanostructures, (2) zero-, one-, two- and three-dimensional nanostructures, (3) characterization and properties of nanomaterials, and (4) application of nanoscale devices. Prerequisites: graduate standing in Engineering and Science.

ECE 874. Semiconductor Characterization. 3 Credits.

Introduction of basic methods for semiconductor material and device characterization. Topics include resistivity, carrier doping concentration, contact resistance, Schottky barrier height, series resistance, channel length, threshold voltage, mobility, oxide and interface trapped charge, deep level impurities, carrier lifetime, and optical, chemical and physical characterization. Prerequisites: ECE 473 or ECE 573 or equivalent.

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This course covers the fundamental principals governing low temperature plasma discharges and their applications. First the fundamental properties of plasmas are introduced. These include the kinetic theory of gases, collisional processes, and plasma sheaths. Then in-depth coverage of the physical mechanisms underlying the operation of non-equilibrium plasma discharges is presented, including important characteristics such as their ignition, evolution, and eventual quenching. Finally, practical applications of non-thermal plasmas, including applications in biology and medicine, are presented. Prerequisites: graduate standing.

ECE 877. Semiconductor Process Technology. 3 Credits.

Theory, design and fabrication of modern integrated circuits that consist of nano scale devices and materials. Topics include crystal growth and wafer preparation process including epitaxy, thin film deposition, oxidation, diffusion, ion implantation, lithography, dry etching, VLSI process integration, diagnostic assembly and packaging, yield and reliability. Prerequisites: ECE 473 or ECE 573.

ECE 880. Machine Learning II. 3 Credits.

Advanced topics in machine learning and pattern recognition systems. Data reduction techniques including principle component analysis, independent component analysis and manifold learning. Introduction to sparse coding and deep learning for data representation and feature extraction. Prerequisites: ECE 607 or equivalent.

ECE 882. Digital Signal Processing II. 3 Credits.

Review of time domain and frequency domain analysis of discrete time signals and systems. Fast Fourier Transforms, recursive and non-recursive digital filter analysis and design, multirate signal processing, optimal linear filters, and power spectral estimation. Prerequisites: ECE 612 or equivalent.

ECE 883. Digital Image Processing. 3 Credits.

Principles and techniques of two-dimensional processing of images. Concepts of scale and spatial frequency. Image filtering in spatial and transform domains. Applications include image enhancement and restoration, image compressing, and image segmentation for computer vision. Prerequisites: ECE 381 or ECE 612 or ECE 782 or ECE 882.

ECE 884. Computer Vision. 3 Credits.

Principles and applications of computer vision, advanced image processing techniques as applied to computer vision problems, shape analysis and object recognition. Prerequisite: Graduate standing.

ECE 887. Digital Communications. 3 Credits.

Fundamental concepts of digital communication and information transmission: information sources and source coding; orthonormal expansions of signals, basis functions, and signal space concepts; digital modulation techniques including PAM, QAM, PSK and FSK; matched filters, demodulation and optimal detection of symbols and sequences; bandwidth; mathematical modeling of communication channels; channel capacity. Prerequisites: ECE 451/ECE 551 or equivalent or permission of the instructor.

ECE 892. Doctor of Engineering Project. 1-12 Credits.

Directed individual study applying advanced level technical knowledge to identify, formulate, and solve a complex, novel problem in electrical and computer engineering.

ECE 895. Topics in Electrical and Computer Engineering. 3 Credits.

Topics in Electrical and Computer Engineering. Prerequisites: departmental approval.

ECE 896. Topics in Electrical and Computer Engineering. 3 Credits.

Topics in Electrical and Computer Engineering.

ECE 897. Independent Study. 1-3 Credits.

This course allows students to develop specialized expertise by independent study (supervised by a faculty member) Prerequisites: departmental approval.

ECE 899. Dissertation Research. 1-9 Credits.

Directed research for the doctoral dissertation. Prerequisites: departmental approval.

ECE 998. Master's Graduate Credit. 1 Credit.

This course is a pass/fail course for master's students in their final semester. It may be taken to fulfill the registration requirement necessary for graduation. All master's students are required to be registered for at least one graduate credit hour in the semester of their graduation.

ECE 999. Doctoral Graduate Credit. 1 Credit.

This course is a pass/fail course doctoral students may take to maintain active status after successfully passing the candidacy examination. All doctoral students are required to be registered for at least one graduate credit hour every semester until their graduation.

MODELING AND SIMULATION Courses**MSIM 506. Introduction to Distributed Simulation. 3 Credits.**

An introduction to distributed simulation. Topics include motivation for using distributed simulation, distributed simulation architectures, time management issues, and distributed simulation approaches. Current standards for distributed simulation are presented. Prerequisites: MSIM 331 or ECE 348.

MSIM 508. Introduction to Game Development. 3 Credits.

Requires an understanding of physics and either CS 361 or MSIM 331. An introductory course focused on game development theory and modern practices with emphasis on educational game development. Topics include game architecture, computer graphics theory, user interaction, audio, high level shading language, animation, physics, and artificial intelligence. The developed games can run on a variety of computer, mobile, and gaming platforms.

MSIM 510. Model Engineering. 3 Credits.

The goal of this course is to develop understanding of the various modeling paradigms appropriate for capturing system behavior and conducting digital computer simulation of many types of systems. The techniques and concepts discussed typically include UML, concept graphs, Bayesian nets, Markov models, Petri nets, system dynamics, Bond graphs, etc. Students will report on a particular technique and team to implement a chosen system model. (cross-listed with ECE 510).

MSIM 516. Cyber Defense Fundamentals. 3 Credits.

This course focuses on cybersecurity theory, information protection and assurance, and computer systems and networks security. The objectives are to understand the basic security models and concepts, learn fundamental knowledge and tools for building, analyzing, and attacking modern security systems, and gain hands-on experience in cryptographic algorithms, security fundamental principles, and Internet security protocol and standards. Cross-listed with ECE 516.

MSIM 519. Cyber Physical Systems Security. 3 Credits.

Cyber Physical Systems (CPS) integrate computing, networking, and physical processes. The objectives of this course are to learn the basic concepts, technologies and applications of CPS, understand the fundamental CPS security challenges and national security impact, and gain hands-on experience in CPS infrastructures, critical vulnerabilities, and practical countermeasures. Cross-listed with ECE 519.

MSIM 541. Computer Graphics and Visualization. 3 Credits.

The course provides a practical treatment of computer graphics and visualization with emphasis on modeling and simulation applications. It covers digital image and signal processing basics such as sampling and discrete Fourier transform, computer graphics fundamentals, visualization principles, and software architecture for visualization in modeling and simulation. Written communication and information literacy skills are stressed in this course. (Cross listed with ECE 506.) (Offered fall)
Prerequisites: a grade of C or better in CS 381 or ECE 348.

MSIM 551. Analysis for Modeling and Simulation. 3 Credits.

An introduction to analysis techniques appropriate to the conduct of modeling and simulation studies. Topics include input modeling, random number generation, output analysis, variance reduction techniques, and experimental design. In addition, techniques for verification & validation are introduced. Course concepts are applied to real systems and data.
Prerequisites: MSIM 205 or ECE 306 and STAT 330 or ECE 304.

MSIM 562. Introduction to Medical Image Analysis. 3 Credits.

Introduction to basic concepts in medical image analysis. Medical image registration, segmentation, feature extraction, and classification are discussed. Basic psychophysics, fundamental ROC analysis and FROC methodologies are covered. Cross-listed with ECE 462/ECE 562.

MSIM 563. Design and Modeling of Autonomous Robotic Systems. 3 Credits.

Course focuses on autonomous robotics systems with emphasis on using modeling and simulation (M&S) for system level design and testing. Fundamental concepts associated with autonomous robotic systems are discussed. Course topics include: robotic control, architectures, and sensors as well as more advanced concepts such as error propagation, localization, mapping and autonomy. Design strategies that leverage M&S to accelerate the development and testing of sophisticated autonomous robotic algorithms for individual or teams of robots are covered. Prerequisite: CS 150 or ENGN 150.

MSIM 570. Foundations of Cyber Security. 3 Credits.

Course provides an overview of theory, tools and practice of cyber security and information assurance through prevention, detection and modeling of cyber attacks and recovery from such attacks. Techniques for security modeling, attack modeling, risk analysis and cost-benefit analysis are described to manage the security of cyber systems. Fundamental principles of cyber security and their applications for protecting software and information assets of individual computers and large networked systems are explored. Anatomy of some sample attacks designed to compromise confidentiality, integrity and availability of cyber systems are discussed.
Prerequisites: CS 150 or ENGN 150.

MSIM 574. Transportation Data Analytics. 3 Credits.

This course presents the basic techniques for transportation data analytics. It will discuss statistical modeling, prominent algorithms, and visualization approaches to analyze both small- and large-scale data sets generated from transportation systems. Practices of using different data for various real-world traffic/transportation applications and decision making will also be discussed. Prerequisites: Basic probability and statistics (e.g., STAT 330 or ECE 304); any programming language such as C, Python or Java is beneficial but not required.

MSIM 580. Introduction to Artificial Intelligence. 3 Credits.

Introduction to concepts, principles, challenges, and research in major areas of artificial intelligence. Areas of discussion include: natural language and vision processing, machine learning, machine logic and reasoning, robotics, expert and mundane systems. Laboratory work required. Prerequisite: Instructor approval.

MSIM 595. Topics in Modeling and Simulation Engineering. 3 Credits.

Special topics of interest with emphasis placed on recent developments in modeling and simulation engineering.

MSIM 596. Topics in Modeling and Simulation Engineering. 1-3 Credits.

Special topics of interest with emphasis placed on the recent developments in modeling and simulation engineering. Prerequisites: permission of the instructor.

MSIM 597. Independent Study in Modeling and Simulation Engineering. 3 Credits.

Individual analytical, computational, and/or experimental study in an area selected by the student. Supervised and approved by the advisor.

MSIM 601. Introduction to Modeling and Simulation. 3 Credits.

Modeling and simulation (M&S) discipline surveyed at an overview level of detail. Basic terminology, modeling methods, and simulation paradigms are introduced. Applications of M&S in various disciplines are discussed. The course provides a general conceptual framework for those interested in using M&S and for further studies in M&S. Not open to MSVE degree seeking students. Prerequisites: graduate standing; undergraduate exposure to calculus and probability & statistics.

MSIM 602. Simulation Fundamentals. 3 Credits.

An introduction to the modeling and simulation discipline. Introduction to discrete event simulation (DES) including simulation methodology, input data modeling, output data analysis, and an overview of DES tools. Introduction to continuous simulation (CS) including simulation methodology, differential equation models, numerical solution techniques, and an overview of CS tools. Prerequisites: graduate standing; undergraduate preparation in calculus and probability & statistics; and computer literacy.

MSIM 603. Simulation Design. 3 Credits.

Course develops the computer software skills necessary for the design and development of simulation software. Topics covered include software architectures, software engineering, software design, object-oriented programming, abstract data types and classes, data structures, algorithms, and testing and debugging techniques. Software design and development of simulation systems (discrete-event, continuous, and Monte Carlo) are emphasized. Prerequisite: MSIM 602 and an introductory computer programming course.

MSIM 607. Machine Learning I. 3 Credits.

Course provides a practical treatment of design, analysis, implementation and applications of algorithms. Topics include multiple learning models: linear models, neural networks, support vector machines, instance-based learning, Bayesian learning, genetic algorithms, ensemble learning, reinforcement learning, unsupervised learning, etc. (Cross listed with ECE 607).

MSIM 660. System Architecture and Modeling. 3 Credits.

Students will learn the essential aspects of the system architecture paradigm through environment and analysis of multiple architecture framework and enterprise engineering, such as IDEFO, TOGAF, DODAF and OPM. Emphasis on system modeling and enterprise engineering. (Cross listed with ENMA 660).

MSIM 667. Cooperative Education. 1-3 Credits.

Available for pass/fail grading only. Student participation for credit based on academic relevance of the work experience, criteria, and evaluation procedures as formally determined by the program and the Cooperative Education/Career Development Services program prior to the semester in which the work experience is to take place.

MSIM 668. Internship. 1-3 Credits.

Academic requirements will be established by the department and will vary with the amount of credit desired. Allows students an opportunity to gain short duration career-related experience. Prerequisites: Approval by department and Career Development Services.

MSIM 669. Practicum. 1-3 Credits.

Academic requirements will be established by the graduate program director and will vary with the amount of credit desired. Allows students an opportunity to gain short-duration career related experience. Student is usually employed—this is an additional project beyond the duties of the student's employment.

MSIM 670. Cyber Systems Engineering. 3 Credits.

This course provides an overview of functioning of cyber systems including how a computer interacts with the outside world. The composition of critical infrastructure and functioning of different engineered systems that form critical infrastructure are discussed. Mutual dependence and interactions between cyber systems and other engineered systems and the resulting security risks are also explored. (Cross-listed with ENMA 670.).

MSIM 673. Threat Modeling and Risk Analysis. 3 Credits.

This course discusses how to develop cyber threat models using attack graphs/trees, STRIDE, Universal Modeling Language (UML), attack graphs/trees and common of risk analysis tools. Course also discusses the need for quantitative security analysis and formal validation of security models and basic principles of formal model validation. (Cross-listed with ENMA 673.).

MSIM 695. Topics in Modeling and Simulation. 3 Credits.

Special topics of interest with emphasis placed on recent developments in modeling and simulation.

MSIM 697. Independent Study in Modeling and Simulation. 3 Credits.

Individual study selected by the student. Supervised and approved by a faculty member with the approval of the graduate program director. Prerequisites: permission of instructor or graduate program director.

MSIM 699. Thesis. 1-6 Credits.

Research leading to the Master of Science thesis. Prerequisites: permission of instructor and graduate program director.

MSIM 702. Systemic Decision Making. 3 Credits.

As machine age problems have given way to systems age messes, the underlying complexity associated with understanding these situations has increased exponentially. Accordingly, the methods we use to address these situations must evolve as well. This course will introduce students to a method for thinking holistically about problems and messes conceptually founded in systems theory. This paradigm, known as systemic thinking, will be contrasted with traditional systematic thinking, and practical guidelines for the deployment of a systemic thinking approach will be provided. This paradigm will increase the student's ability to make rational decisions in complex environments. (Cross listed with ENMA 702).

MSIM 703. Optimization Methods. 3 Credits.

Covers advanced methods in Operations Research and Optimization. Focus will be on developing models and their applications in different domains including manufacturing and service. Modern optimization tools will be used to implement models for case studies, projects and research papers. The knowledge of programming and spreadsheets is expected. Contact instructor for more details. (Cross-listed with ENMA 703).

MSIM 711. Finite Element Analysis. 3 Credits.

The purpose of the course is to provide an understanding of the finite element method (FEM) as derived from an integral formulation perspective. The course will demonstrate the solutions of (1-D and 2-D) continuum mechanics problems such as solid mechanics, fluid mechanics and heat transfer. Prerequisites: permission of the instructor.

MSIM 715. High Performance Computing and Simulations. 3 Credits.

Introduction to modern high performance computing platforms including top supercomputers and accelerators. Discussion of parallel architectures, performance, programming models, and software development issues. Case studies of scientific and engineering simulations will be explored. Students will have an opportunity to work on parallelization of problems from their research areas. Project presentations are required.

MSIM 722. Cluster Parallel Computing. 3 Credits.

This course provides detailed numerical step-by-step procedures to exploit parallel and sparse computation under MPI (Message Passing Interface) computer environments. Large-scale engineering/science applications are emphasized. Simultaneous linear equations are discussed.

MSIM 725. Principles of Combat Modeling and Simulation. 3 Credits.

Principles of combat modeling and simulation. Introduction including history, basic definitions, and best practice. Algorithms for modeling movement, sensing effects and behavior. Overview of modern combat models. Interoperability and integration into operational environments. Prerequisites: MSIM 603.

MSIM 730. Simulation Formalisms. 3 Credits.

The focus of the course is on identification and investigation of mathematical and logical structures that form the foundation for computational simulation. Topics include: foundations of simulation theory in logic, discrete mathematics, and computability; simulation formalisms, including DEVS; interoperability protocols; and computational complexity.

MSIM 741. Principles of Visualization. 3 Credits.

Well-designed graphical media capitalizes on human facilities for processing visual information and thereby improves comprehension, memory, inference, and decision making. This course teaches techniques and algorithms for creating effective visualizations based on principles and techniques from graphic design, visual art, perceptual psychology and cognitive science. Both users and developers of visualization tools and systems will benefit from this course.

MSIM 742. Synthetic Environments. 3 Credits.

The course covers the theory and techniques for building effective and efficient synthetic environments for modeling and simulation applications. Topics include physics, artificial intelligence, virtual reality, and advanced modeling and rendering. The emphasis is on producing visually realistic synthetic environments based on effective approximations of physics and other related principles. Prerequisites: MSIM 541 or equivalent.

MSIM 751. Advanced Analysis for Modeling and Simulation. 3 Credits.

An introduction to stochastic dependence and Bayesian analysis techniques for conducting modeling and simulation studies. Topics include: measures of dependence, common multivariate distributions, sampling from multivariate distributions, elementary time series models and Bayesian statistics. Prerequisites: MSIM 451 or MSIM 551.

MSIM 762. Applied Medical Image Analysis. 3 Credits.

Course explores hands-on exposure to state-of-the-art algorithms in medical image analysis, which builds on open-source software (Insight Segmentation and Registration Toolkit - ITK), as well as the principles of medical image acquisition in the modalities of clinical interest. Medical imaging modalities - X-rays, CT, and MRI/ITK image pipeline; image enhancement, feature detection; segmentation - basic techniques, feature-based classification and clustering, graph cuts, active contour and surface models; surface and volume meshing; registration - transformations, similarity criteria; shape and appearance models are all explored and discussed in this course. Prerequisites: Knowledge of C++ and object-oriented programming.

MSIM 772. Modeling Global Events. 3 Credits.

Modeling Global Events introduces modeling and simulation as a tool for expanding our understanding of events that have shaped the global environment of the 21st century. Students will review real-world case studies and then analyze these case studies via system dynamics, agent-based, social network, and game theory modeling paradigms. This course is designed to develop empirical research skills, conceptual modeling expertise, and model construction. Students will understand how to analyze, verify, and validate a model.

MSIM 774. Transportation Network Flow Models. 3 Credits.

This course provides a rigorous introduction to transportation network modeling, with special emphasis on network equilibrium problems. Topics include: elementary graph theory, shortest path problem nonlinear optimization, optimization of univariate functions, deterministic and stochastic user equilibrium. (Cross-listed with CEE 774).

MSIM 775. Transportation Network Algorithms. 3 Credits.

Fundamental models and algorithms in optimization, stochastic modeling and parallel computing will be discussed and illustrated with transportation applications. (Cross-listed with CEE 775).

MSIM 776. Simulation Modeling in Transportation Networks. 3 Credits.

Principles of simulation modeling, microscopic, mesoscopic, and macroscopic traffic simulation models. Course explores diver behavior in networks, calibration and validation of traffic simulation models, and use of traffic simulation software. (Cross-listed with CEE 776).

MSIM 780. Machine Learning II. 3 Credits.

Advanced topics in machine learning and pattern recognition systems. Data reduction techniques including principle component analysis, independent component analysis and manifold learning. Introduction to sparse coding and deep learning for data representation and feature extraction. (Cross-listed with ECE 780) Prerequisite: MSIM 607 or equivalent.

MSIM 795. Topics in Modeling and Simulation. 3 Credits.

Special topics of interest with emphasis placed on recent developments in modeling and simulation.

MSIM 797. Independent Study in Modeling and Simulation. 3 Credits.

Individual study selected by the student. Supervised and approved by a faculty member with the approval of the graduate program director. Prerequisites: permission of instructor or graduate program director.

MSIM 802. Systemic Decision Making. 3 Credits.

As machine age problems have given way to systems age messes, the underlying complexity associated with understanding these situations has increased exponentially. Accordingly, the methods we use to address these situations must evolve as well. This course will introduce students to a method for thinking holistically about problems and messes conceptually founded in systems theory. This paradigm, known as systemic thinking, will be contrasted with traditional systematic thinking, and practical guidelines for the deployment of a systemic thinking approach will be provided. This paradigm will increase the student's ability to make rational decisions in complex environments. (Cross listed with ENMA 802).

MSIM 803. Optimization Methods. 3 Credits.

Covers advanced methods in Operations Research and Optimization. Focus will be on developing models and their applications in different domains including manufacturing and service. Modern optimization tools will be used to implement models for case studies, projects and research papers. The knowledge of programming and spreadsheets is expected. Contact instructor for more details. (Cross-listed with ENMA 803).

MSIM 811. Finite Element Analysis. 3 Credits.

The purpose of the course is to provide an understanding of the finite element method (FEM) as derived from an integral formulation perspective. The course will demonstrate the solutions of (1-D and 2-D) continuum mechanics problems such as solid mechanics, fluid mechanics and heat transfer. Prerequisites: permission of the instructor.

MSIM 815. High Performance Computing and Simulations. 3 Credits.

Introduction to modern high performance computing platforms including top supercomputers and accelerators. Discussion of parallel architectures, performance, programming models, and software development issues. Case studies of scientific and engineering simulations will be explored. Students will have an opportunity to work on parallelization of problems from their research areas. Project presentations are required.

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The focus of the course is on identification and investigation of mathematical and logical structures that form the foundation for computational simulation. Topics include: foundations of simulation theory in logic, discrete mathematics, and computability; simulation formalisms, including DEVS; interoperability protocols; and computational complexity.

MSIM 841. Principles of Visualization. 3 Credits.

Well-designed graphical media capitalizes on human facilities for processing visual information and thereby improves comprehension, memory, inference, and decision making. This course teaches techniques and algorithms for creating effective visualizations based on principles and techniques from graphic design, visual art, perceptual psychology and cognitive science. Both users and developers of visualization tools and systems will benefit from this course.

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MSIM 851. Advanced Analysis for Modeling and Simulation. 3 Credits.

An introduction to stochastic dependence and Bayesian analysis techniques for conducting modeling and simulation studies. Topics include: measures of dependence, common multivariate distributions, sampling from multivariate distributions, elementary time series models and Bayesian statistics. Prerequisites: MSIM 451 or MSIM 551.

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MSIM 872. Modeling Global Events. 3 Credits.

Modeling Global Events introduces modeling and simulation as a tool for expanding our understanding of events that have shaped the global environment of the 21st century. Students will review real-world case studies and then analyze these case studies via system dynamics, agent-based, social network, and game theory modeling paradigms. This course is designed to develop empirical research skills, conceptual modeling expertise, and model construction. Students will understand how to analyze, verify, and validate a model.

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MSIM 875. Transportation Network Algorithms. 3 Credits.

Fundamental models and algorithms in optimization, stochastic modeling and parallel computing will be discussed and illustrated with transportation applications. (Cross-listed with CEE 875).

MSIM 876. Simulation Modeling in Transportation Networks. 3 Credits.

Principles of simulation modeling, microscopic, mesoscopic, and macroscopic traffic simulation models. Course explores driver behavior in networks, calibration and validation of traffic simulation models, and use of traffic simulation software. (Cross-listed with CEE 876).

MSIM 880. Machine Learning II. 3 Credits.

Advanced topics in machine learning and pattern recognition systems. Data reduction techniques including principle component analysis, independent component analysis and manifold learning. Introduction to sparse coding and deep learning for data representation and feature extraction. (Cross-listed with ECE 880) Prerequisite: MSIM 607 or equivalent.

MSIM 892. Doctor of Engineering Project. 1-9 Credits.

Directed individual study applying advanced level technical knowledge to identify, formulate and solve a complex, novel problem in Modeling and Simulation.

MSIM 895. Topics in Modeling and Simulation. 3 Credits.

Special topics of interest with emphasis placed on recent developments in modeling and simulation.

MSIM 897. Independent Study in Modeling and Simulation. 1-3 Credits.

Individual study selected by the student. Supervised and approved by a faculty member with the approval of the graduate program director. Prerequisites: permission of the instructor or graduate program director.

MSIM 898. Research in Modeling and Simulation. 1-12 Credits.

Supervised research prior to passing Ph.D. candidacy exam. Prerequisites: permission of the instructor and graduate program director.

MSIM 899. Dissertation. 1-12 Credits.

Directed research for the doctoral dissertation. Prerequisites: permission of the instructor and graduate program director.

MSIM 998. Master's Graduate Credit. 1 Credit.

This course is a pass/fail course for master's students in their final semester. It may be taken to fulfill the registration requirement necessary for graduation. All master's students are required to be registered for at least one graduate credit hour in the semester of their graduation.

MSIM 999. Doctoral Graduate Credit. 1 Credit.

This course is a pass/fail course doctoral students may take to maintain active status after successfully passing the candidacy examination. All doctoral students are required to be registered for at least one graduate credit hour every semester until their graduation.