Welcome to Johns Hopkins University’s Engineering for Professionals (EP).

As part of the Whiting School of Engineering, EP programs draw on Johns Hopkins’ world-renowned strengths in research and education to provide working engineers with academic opportunities of a breadth and quality unparalleled in higher education.

The Whiting School has long been committed to serving the educational needs of working engineers in the Baltimore-Washington region. Success in this area, combined with the ability to respond to industry’s evolving demands, has made EP a national leader in its field. The knowledge and skills that EP students acquire have consistently been the catalysts for their career advancement. Today, EP alumni can be found in management and technical leadership positions in both public and private sectors.

EP’s comprehensive academic offerings include 15 master’s degree programs and advanced certificates in many areas of study. Through online courses and a growing number of academic/industrial partnerships, EP has further broadened its reach to provide educational programs of the highest quality to students from across the nation and around the world.

EP’s reputation for academic excellence is due, in large part, to the quality of its faculty. Thanks to faculty members’ strong relationships with industry and leading private and government organizations, as well as affiliation with The Johns Hopkins University Applied Physics Laboratory, EP students are taught by some of the nation’s most accomplished engineers, scientists, and researchers. These professionals work at the cutting edge of their fields and know first-hand what it takes to be leaders in today’s competitive marketplace. EP’s faculty members draw on their knowledge of current technologies, practices, and unique professional experiences to enrich their academic programs. They balance theory with application and provide students with a strong command of underlying engineering principles.

EP is excited to partner with the Carey Business School for three distinct dual degree programs within the Environmental Engineering, Science, and Management program. Online course offerings continue to grow and EP now offers more than 100 courses across multiple disciplines, including online master’s degree programs in Systems Engineering, Computer Science, Environmental Planning and Management, Environmental Engineering and Science, Cybersecurity, Information Systems Engineering, and Bioinformatics.

I invite you to learn more about EP and how a Johns Hopkins Engineering degree or advanced certificate can help you achieve your professional goals. And, again, welcome to the Johns Hopkins engineering community.

Sincerely,

Nicholas P. Jones
Benjamin T. Rome Dean
Whiting School of Engineering
# 2013–2014 Academic Calendar

**Application Deadline:** The admissions process is handled on a continuing basis.

<table>
<thead>
<tr>
<th>Important Semester Dates:</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Day of Classes</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Last Day of Classes</td>
</tr>
<tr>
<td>Graduation Application Deadlines</td>
</tr>
<tr>
<td>Holidays</td>
</tr>
</tbody>
</table>

**Registration Deadlines**

<table>
<thead>
<tr>
<th>Registration Opens</th>
<th>Summer 2013</th>
<th>Fall 2013</th>
<th>Spring 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Registration Closes</td>
<td>May 24</td>
<td>August 30</td>
<td>January 24</td>
</tr>
<tr>
<td>Final Day to Add</td>
<td>2nd class meeting</td>
<td>September 17</td>
<td>February 9</td>
</tr>
<tr>
<td>Final Day to Add Online Courses</td>
<td>June 5</td>
<td>September 10</td>
<td>February 2</td>
</tr>
<tr>
<td>Withdrawal/Audit Deadline</td>
<td>9th class meeting</td>
<td>November 10</td>
<td>April 5</td>
</tr>
</tbody>
</table>

**Tuition Payment Deadlines***

<table>
<thead>
<tr>
<th>Tuition Payment Deadlines*</th>
<th>Summer 2013</th>
<th>Fall 2013</th>
<th>Spring 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 11</td>
<td>September 17</td>
<td>February 10</td>
<td></td>
</tr>
</tbody>
</table>

*There will be a $150 late fee if tuition is not paid by the due date.

Whiting School Graduate Ceremony is Wednesday, May 21, 2014.

University Commencement Day is Thursday, May 22, 2014.
Contact Information

Johns Hopkins Engineering for Professionals
Dorsey Student Services Center
6810 Deerpath Road, Suite 100
Elkridge, MD 21075
410-516-2300
ep.jhu.edu

General Information and Requests
Admissions/Registration (Dorsey Student Services Center) ......................... 410-516-2300

Education Centers
Applied Physics Lab (from Baltimore) ..................................................... 443-778-6510
(from Washington) ............................................................................. 240-228-6510
Crystal City Center ............................................................................. 240-228-2912
Dorsey Student Services Center........................................................... 410-516-2300
Higher Education and Conference Center @ HEAT.............................. 443-360-9200
Homewood Campus ............................................................................. 410-516-8000
Montgomery County Campus ............................................................. 301-294-7070
Southern Maryland Center ................................................................. 301-737-2500
Washington, DC, Center .................................................................... 202-588-0590

Student Services
Disability Services ............................................................................. 410-516-2306
Financial Aid (146 Garland Hall) .......................................................... 410-516-8028
International Office ............................................................................ 410-516-1013
JH Student Assistance Program ........................................................... 443-287-7000
University Registrar (75 Garland Hall) ................................................ 410-516-8083
Student Accounts (EP) ..................................................................... 410-516-2276
Student Accounts (Homewood) ......................................................... 410-516-8158
Transcripts (75 Garland Hall) ............................................................... 410-516-7088
Veterans Certification (75 Garland Hall) ............................................. 410-516-7071

Online Information
Catalog .............................................................................................. catalog.ep.jhu.edu
Application ....................................................................................... ep.jhu.edu/apply
Course Schedule ................................................................................ ep.jhu.edu/schedule
Graduation Information .................................................................... ep.jhu.edu/graduation
EP Forms ......................................................................................... ep.jhu.edu/student-forms

Textbooks
All Locations ..................................................................................... ep.jhu.edu/textbooks

Information in this catalog is current as of publication in March 2013. For all updates, please visit ep.jhu.edu.

The university of necessity reserves the freedom to change without notice any programs, requirements, or regulations published in this catalog. This catalog is not to be regarded as a contract. Multiple means of communication may be used by the university for announcing changes of this nature, including, but not exclusive to, e-mail and/or paper notice. Students are responsible for providing current e-mail and mailing address information to the university administrative offices.
Engineering Administration

Whiting School of Engineering
Nicholas P. Jones, Benjamin T. Rome Dean

Engineering for Professionals
Dexter G. Smith, Associate Dean
Dan Horn, Assistant Dean of Academic Programs
Doug Schiller, Director, Admissions and Student Services
Tim Jarrett, Director, Software Engineering
Mary Kelty, Director, Instructional Technology and Distance Learning
Marielle Nuzback, Senior Director of Operations
Ken Schappelle, Communications and Marketing Manager

APL Education Center
Harry K. Charles, Jr., Director (Acting)
Christine M. Morris, Partnership Manager
Tracy K. Gauthier, Operations Manager

Graduate Program Administration
James C. Spall
Program Chair, Applied and Computational Mathematics
Eileen Haase
Program Chair, Applied Biomedical Engineering
Harry K. Charles Jr.
Program Chair, Applied Physics
Michael Betenbaugh
Program Chair, Chemical and Biomolecular Engineering
Rachel Sangree
Program Chair, Civil Engineering
Brian K. Jennison
Program Chair, Electrical and Computer Engineering
Hedy V. Alavi
Program Chair, Environmental Engineering, Science, and Management

Thomas Longstaff
Program Chair, Computer Science
Program Chair, Cybersecurity
Program Chair, Information Systems Engineering
Robert C. Cammarata
Program Chair, Materials Science and Engineering
Andrea Prosperetti
Program Chair, Mechanical Engineering
Ronald R. Luman
Program Chair, Systems Engineering
Joseph J. Suter
Program Chair, Technical Management
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Computer Science instructor Cheryl Resch, Applied and Computational Mathematics Program Chair Jim Spall and instructor Jacqueline Akinpelu, and Ed Scheinerman, Vice Dean for Education at the Whiting School of Engineering, discuss active learning strategies for students to improve critical thinking skills and mastery of course material at the Annual Faculty Meeting held at the Johns Hopkins Applied Physics Laboratory Kossiakoff Center in March.

Faculty learn about iPad apps that allow them to adapt to an ever-changing, and increasingly paperless, learning environment at the Annual Faculty Meeting held at the Johns Hopkins Applied Physics Laboratory Kossiakoff Center in March.
The Johns Hopkins Distinction

The Johns Hopkins University opened in 1876, with the inauguration of its first president, Daniel Coit Gilman. “What are we aiming at?” Gilman asked in his installation address. “The encouragement of research . . . and the advancement of individual scholars, who by their excellence will advance the sciences they pursue, and the society where they dwell.”

The mission laid out by Gilman remains the university’s mission today, summed up in a simple but powerful restatement of Gilman’s own words: “Knowledge for the world.”

What Gilman created was a research university, dedicated to advancing both students’ knowledge and the state of human knowledge through research and scholarship. Gilman believed that teaching and research are interdependent, that success in one depends on success in the other. A modern university, he believed, must do both well. The realization of Gilman’s philosophy at Johns Hopkins, and at other institutions that later attracted Hopkins-trained scholars, revolutionized higher education in America, leading to the research university system as it exists today.

After more than 130 years, Johns Hopkins remains a world leader in both teaching and research. Eminent professors mentor top students in the arts and music, the humanities, the social and natural sciences, international studies, education, business, and the health professions. Those same faculty members, and their research colleagues at the university’s Applied Physics Laboratory, have each year since 1979 won Johns Hopkins more federal research and development funding than any other university.

Johns Hopkins University is accredited by the Middle States Commission on Higher Education and is privately endowed. Nine divisions of the university grant degrees. They are the Whiting School of Engineering (WSE), the Krieger School of Arts and Sciences, the School of Education, the School of Medicine, the School of Nursing, the Bloomberg School of Public Health, the Peabody Institute, the Carey Business School, and the Paul H. Nitze School of Advanced International Studies. The 10th division of the university is the Applied Physics Laboratory (APL), a research institute.

Whiting School of Engineering

The school consists of the following full-time departments: Applied Mathematics and Statistics, Chemical and Biomolecular Engineering, Civil Engineering, Computer Science, Electrical and Computer Engineering, Geography and Environmental Engineering, Materials Science and Engineering, Mechanical Engineering, and, in collaboration with the School of Medicine, Biomedical Engineering. Information about full-time education may be found in the Johns Hopkins University Arts and Sciences/Engineering Undergraduate and Graduate Catalog or on the web at engineering.jhu.edu. Admission information for full-time undergraduate education is available from the Office of Admissions, Mason Hall, 3400 N. Charles Street, Homewood Campus, 410-516-8171. For full-time graduate education, students should contact the department in which they are interested.

The university has offered part-time engineering education since before World War I. Over the intervening decades, thousands of working engineers and scientists have earned graduate and undergraduate degrees through part-time study, achieving personal and professional goals without interrupting their careers. Today, through the Johns Hopkins Engineering for Professionals program (EP), the Whiting School continues the university’s tradition of offering advanced engineering education to working professionals.

EP courses are continually updated for relevance, addressing industry trends and the latest advances in engineering and applied science fields. Classes are scheduled at convenient times during late afternoons, evenings, and Saturdays and at a number of locations throughout the Baltimore-Washington region. Also, each year, EP offers an increasing number of courses and degree programs online to allow professionals who cannot attend classes at our education centers the ability to advance their education.
Graduate Programs

Graduate students in the Engineering for Professionals (EP) program constitute one of the nation’s largest student bodies in continuing engineering education at the master’s degree level. Graduate courses are offered at eight locations and online. Students receive individual attention from their advisors and instructors and benefit from small classes and well-equipped laboratory, computing, and classroom facilities.

Almost all courses are scheduled in the late afternoon or evening Monday through Friday, on Saturdays, or online, so that students can further their education without interrupting their careers. Graduate students may take courses at any Hopkins location listed in the table at the end of this section. Please note that all courses are not offered at all locations.

The university is accredited by the Middle States Commission on Higher Education, 3624 Market St., Philadelphia, Pa. 19104-2680; 215-662-5606. The Accreditation Board for Engineering and Technology (ABET) is the accrediting authority for engineering and technology programs in the United States. Universities and colleges may choose to have their basic (undergraduate) or advanced (graduate) programs accredited. Nearly every engineering school, including the Whiting School, chooses to have its basic programs accredited by ABET.

Degrees and Certificates

The Johns Hopkins University offers a variety of degrees and certificates to students in the Whiting School of Engineering (WSE). Requirements for each discipline are detailed in the individual program listings in this catalog.

Master of Science

Programs are offered in Applied and Computational Mathematics; Applied Biomedical Engineering; Applied Physics; Computer Science; Electrical and Computer Engineering; Environmental Engineering, Science, and Management; Cybersecurity; Information Systems Engineering; Systems Engineering; and Technical Management.

Master of Engineering

Graduate degree programs are offered in chemical and biomolecular engineering, civil engineering, environmental engineering, materials science and engineering, and mechanical engineering.

Joint Degree and Dual Program

A joint degree in bioinformatics is offered by Engineering for Professionals and the Krieger School of Arts and Sciences (KSAS) Advanced Academic Programs. The description of this degree can be found under Graduate Programs, Bioinformatics program. The administration is handled by KSAS, and applications for admission to the Master of Science in Bioinformatics must be submitted directly to KSAS at bioinformatics.jhu.edu.

A dual program is available, jointly offered by Engineering for Professionals’ Environmental Planning and Management program and the Applied Economics program at Krieger School of Arts and Sciences Advanced Academic Programs (AAP). A detailed description of this program can be found under Graduate Programs, Environmental Engineering, Science, and Management program. Students applying to the dual-degree program will download the application and submit supporting documents and application fee to Advanced Academic Programs at advanced.jhu.edu. The application will be forwarded to EP. Each program decides on admissions separately.

EP’s Environmental Engineering, Science, and Management program offers three dual-degree programs with the Carey Business School. Students may pursue the Master of Environmental Engineering, the Master of Science in Environmental Planning and Management, or the Master of Science in Environmental Engineering and Science, each combining with the Master of Business Administration for three distinct dual-degree programs. A detailed description of these programs can be found under Graduate Programs, Environmental Engineering, Science, and Management program. Students applying to any of the three dual-degree programs will download the application and submit supporting documents and application fee to Engineering for Professionals at ep.jhu.edu. The completed application will be forwarded to the admissions office at the Carey Business School. Each program decides on admissions separately.

Advanced Certificate for Post-Master’s Study

This certificate is awarded upon completion of six courses beyond the master’s degree in the same or a closely related discipline area.

Graduate Certificate

This certificate is awarded upon completion of a select number of courses of graduate study within one of the master’s degree discipline areas.

Non-Degree-Seeking Students

Students who wish to enroll in courses, but are not interested in pursuing a degree or certificate, may enroll as Special Students.
### Programs at a Glance: Offerings by Location and Online

**NOTE:** Graduate students may take courses at any Hopkins location listed in the table. Please note that not all courses are offered at all locations. Locations offering the program are indicated in bold, with the remaining locations offering selected courses. The Program available notation indicates that the program meets the minimum requirement for completing all courses online; it does not mean that all courses within the program are available online.

<table>
<thead>
<tr>
<th>Programs</th>
<th>Locations</th>
<th>Online</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied and Computational Mathematics</td>
<td>• APL&lt;br&gt;• Dorsey Center&lt;br&gt;• Montgomery County Campus</td>
<td>Select courses available</td>
</tr>
<tr>
<td>Applied Biomedical Engineering</td>
<td>• APL&lt;br&gt;• Homewood Campus</td>
<td>Not currently available</td>
</tr>
<tr>
<td>Applied Physics</td>
<td>• APL&lt;br&gt;• Dorsey Center</td>
<td>Not currently available</td>
</tr>
<tr>
<td>Bioinformatics</td>
<td>• APL&lt;br&gt;• Montgomery County Campus</td>
<td>Program available</td>
</tr>
<tr>
<td>Chemical and Biomolecular Engineering</td>
<td>• Homewood Campus</td>
<td>Not currently available</td>
</tr>
<tr>
<td>Civil Engineering</td>
<td>• Dorsey Center&lt;br&gt;• Homewood Campus</td>
<td>Not currently available</td>
</tr>
<tr>
<td>Computer Science</td>
<td>• APL&lt;br&gt;• Dorsey Center&lt;br&gt;• Montgomery County Campus</td>
<td>Program available</td>
</tr>
<tr>
<td>Electrical and Computer Engineering</td>
<td>• APL&lt;br&gt;• Dorsey Center&lt;br&gt;• Montgomery County Campus</td>
<td>Select courses available</td>
</tr>
<tr>
<td>Environmental Engineering, Science, and Management</td>
<td>• APL&lt;br&gt;• Dorsey Center&lt;br&gt;• Homewood Campus</td>
<td>Program available</td>
</tr>
<tr>
<td>Cybersecurity</td>
<td>• APL&lt;br&gt;• Dorsey Center&lt;br&gt;• Montgomery County Campus</td>
<td>Program available</td>
</tr>
<tr>
<td>Information Systems Engineering</td>
<td>• APL&lt;br&gt;• Dorsey Center&lt;br&gt;• Montgomery County Campus</td>
<td>Program available</td>
</tr>
<tr>
<td>Materials Science and Engineering</td>
<td>• APL&lt;br&gt;• Homewood Campus</td>
<td>Not currently available</td>
</tr>
<tr>
<td>Mechanical Engineering</td>
<td>• APL&lt;br&gt;• Dorsey Center</td>
<td>Not currently available</td>
</tr>
<tr>
<td>Systems Engineering</td>
<td>• APL&lt;br&gt;• Crystal City Center&lt;br&gt;• Dorsey Center&lt;br&gt;• Higher Education and Conference Center @ HEAT</td>
<td>Program available</td>
</tr>
<tr>
<td>Technical Management</td>
<td>• APL&lt;br&gt;• Dorsey Center&lt;br&gt;• Montgomery County Campus</td>
<td>Select courses available</td>
</tr>
</tbody>
</table>

### Education Centers

- Applied Physics Laboratory (APL), Laurel, MD
- Dorsey Student Services Center, Elkridge, MD
- Higher Education and Conference Center @ HEAT, Aberdeen, MD
- Homewood Campus, Baltimore, MD
- Montgomery County Campus, Rockville, MD
- Southern Maryland Higher Education Center, California, MD
- Washington, DC, Center, Washington, DC

See [Directions and Maps (page 194)](#).
Online Learning at Engineering for Professionals

EP has been delivering instruction online since 2001 and currently offers more than 140 online courses in the following disciplines:

- Applied and Computational Mathematics;
- Bioinformatics;
- Computer Science;
- Electrical and Computer Engineering;
- Environmental Engineering, Science, and Management;
- Cybersecurity;
- Information Systems Engineering;
- Systems Engineering; and
- Technical Management.

For additional information on the online degree options, please refer to the specific academic program information in this catalog.

EP continues to add new online courses and plans to grow its online program offerings in the areas of applied biomedical engineering; civil, mechanical, and space systems engineering; and technical management.

Online Course Registration

Online course registration adheres to the same schedule followed by on-site courses. Enrollment is granted on a first-come, first-served basis, and new and returning online students are strongly encouraged to register early. The deadline for adding online courses is a week after the first day of classes each term, which is earlier than the deadline for adding conventional courses. See the 2013–2014 Academic Calendar (page ii) for exact dates for each term.

Online Student Support Services

EP makes every effort to provide online students access to a full range of services and resources comparable to those available to students taking on-site courses. Online students can register, pay their tuition, receive academic advising, purchase course textbooks, access JHU library holdings, view transcripts, and access grades and various other academic services all online. Once admitted, students gain access to the Johns Hopkins portal site, myJH, which provides quick access to many of these services.

Services for Students with Disabilities

Students with disabilities should refer to Services for Students with Disabilities (page 13). For questions or concerns regarding university-wide disability issues, contact the Office of Student Disability Services at web.jhu.edu/disabilities/index.html.

Admission Requirements

Johns Hopkins Engineering for Professionals encourages all students who have serious academic interests to apply. Qualified students may structure their coursework to pursue a specific degree or certificate program, or they may take courses under the Special Student (i.e., non-degree-seeking) designation if they have met program and course prerequisites. An applicant may be admitted in one of four categories:

1. Master's Degree candidate
2. Advanced Certificate for Post-Master's Study candidate
3. Graduate Certificate candidate
4. Special Student

An applicant must meet the general admission requirements appropriate for all graduate study and the specific admission requirements for the desired program. Note that these requirements represent minimum standards for admission; the final decision on an applicant's suitability for a given program is made by the admissions committee for that program. The general application procedures and admission requirements are stated below. Please refer to the individual program sections for additional specific requirements.

Applicants who have been dismissed or suspended by any college or university, including Johns Hopkins, within the past four years are not eligible for admission.

Master's Degree Candidates

The program consists of 10 courses planned in consultation with an advisor. Note that the joint MS in Bioinformatics degree requires 11 courses. General admission requirements for master's degree candidates and others seeking graduate status are as follows: applicants must be in the last semester of undergraduate study or hold a bachelor's degree from a regionally accredited college or university. Applicants must have earned grade point averages of at least 3.0 on a 4.0 scale (B or above) in the latter half of their studies or hold graduate degrees in technical disciplines. In considering applications to the Systems Engineering program, both academic record and experience will be considered and, at the discretion of the admissions committee, years and quality of experience may compensate for a GPA that is just short of the required 3.0.

Students must complete the master's degree within five years from the start of the first course in the program. Only one grade of C can count toward the master's degree.

Please note that the programs listed in this catalog may also have additional admission requirements (i.e., beyond the general admission guidelines listed here) specific to the academic program of study.
Advanced Certificate for Post-Master’s Study Candidates
To accommodate students who wish to pursue studies beyond the master’s degree, many of the disciplines in the programs offer a certificate of post-master’s study. This program is intended to add depth, breadth, or both in the discipline of the student’s master’s degree or a closely related one. The program consists of six courses planned in consultation with an advisor. In some cases, students may substitute independent projects for up to two of the courses.

The general admission requirement for the advanced certificate program is that candidates must have completed a master’s degree in an engineering or science discipline. Academic credentials must be submitted for review by the admissions committee. After acceptance, each student is assigned an advisor with whom he or she jointly designs a program tailored to individual educational objectives.

Students must complete the Advanced Certificate for Post-Master’s Study within three years of the first enrollment in the program. Only grades of B– or above can count toward the Advanced Certificate for Post-Master’s Study.

Courses taken for the Advanced Certificate for Post-Master’s Study may be counted toward a master’s degree with advisor approval.

Graduate Certificate Candidates
The graduate certificate is offered in a select number of degree disciplines and is directed toward students who may not need a master’s degree, may not have the opportunity to pursue the entire master’s degree, or may wish to focus their studies on a set of courses in a specific subject area.

The certificate generally consists of five to six courses (program dependent). The program area of study specifies the selection and number of applicable courses. If, in the future, the student decides to pursue a full master’s degree, all courses will apply provided they meet the program requirements and fall within the five-year limit.

Students must meet the general master’s degree admission requirements, as well as the specific requirements of the desired program. Academic credentials must be submitted for admission committee review. After acceptance, each student is assigned an advisor with whom he or she jointly designs a program tailored to individual educational objectives.

Students must complete the Graduate Certificate within three years of first enrolling in the program. Only grades of B or above can count toward the Graduate Certificate.

Courses taken for the Graduate Certificate may be counted toward a master’s degree with advisor approval.

Special Students
The general requirement for admission as a Special Student (i.e., non-degree-seeking) is that the applicant must hold a bachelor’s degree from a regionally accredited college or university or be in the last semester of undergraduate study. Applicants must have earned a grade point average of at least 3.0 on a 4.0 (B or above) scale in the latter half of their studies or hold graduate degrees in relevant technical disciplines and meet admission prerequisites for the program in which they have applied to be a Special Student.

Visiting graduate students are Special Students who are actively enrolled in a graduate program at another university and are registering for EP courses. They must be in good academic and disciplinary standing.

All Special Students must satisfy program prerequisites as well as specific course prerequisites in order to enroll.

Courses taken while a Special Student do not necessarily count toward fulfillment of degree requirements if the student is subsequently accepted as a degree candidate. Determinations on course applicability toward a degree are made on an individual basis.

Application Procedures
To be considered for admission to a degree or certificate program or to take courses as Special Students, applicants must submit a formal application, a nonrefundable $75 application fee made payable to Johns Hopkins University, official transcripts of all college studies, and any other documents specified by particular programs. Additional documents may be required when applying to joint and/or dual-degree programs. If a Special Student applicant later decides to apply for a degree, a letter of intent is required. The application fee is waived for alumni of the Whiting School of Engineering. Generally, EP recommends that students apply for admission in the semester prior to their planned enrollment.

The application is available online at ep.jhu.edu/apply/. Complete instructions are available on the website.

An application for admission is not reviewed by an admissions committee until official transcripts from all colleges attended and required supporting documents are received. Please note that official transcripts must be received in the institution’s sealed envelope or sent electronically via the Scrip-Safe network. Failure to provide all official transcripts, supporting documents, and the application fee will delay review of the application. Please allow four to six weeks for application processing once all materials have been received.

Readmission
An application is held on file for one year from the date of its receipt. Applicants who fail to submit required materials within this period must reapply and submit another application and fee.

Applicants must satisfy admission requirements in force at the time of reapplication. Admitted students may defer the start of their studies for up to one year after admission. After one year of inactivity, the student must reapply.

Applicants who have been dismissed or suspended by any college or university, including Johns Hopkins, within the past four years are not eligible for admission.
Admission to Other Divisions of the University
Any student who wishes to transfer to another school in the university or to a full-time engineering program must apply to the appropriate department or to the Office of Admissions. Admission to an EP program establishes no claim or priority for admission to other divisions of the university.

International Applicants
The United States Immigration and Naturalization Service regulations require students with F-1 visas to be enrolled full-time in a degree-seeking program.

As EP does not provide on-campus housing or financial support for graduate international students, applicants needing student F-1 visas must be able to present documented evidence of available financial support to cover annual living and educational expenses while studying at JHU. Applicants who are in the United States on student visas should consult with their current schools’ international offices for information on how to transfer to another approved school.

EP is not authorized to certify the I-20 form required for a student visa. Those holding student visas granted by other universities are not allowed to register for classes and cannot be accepted as degree candidates or Special Students. For visa information, contact the JHU Office of International Student and Scholar Services at jhu.edu/iss.

International Credential Evaluation
Applicants who hold degrees or have earned credits from non-U.S. institutions must have their academic records evaluated by World Education Services, Inc. before they can be considered for graduate or Special Student status or admission to a degree/certificate program. In addition to submitting official records to EP, applicants must make arrangements with the credential evaluation agency listed below for an evaluation of the degree, an assessment of the overall grade point average, and a course-by-course evaluation.

World Education Services, Inc.
P.O. Box 745
Old Chelsea Station
New York, NY 10113-0745
Telephone: 212-966-6311
Fax: 212-966-6395
E-mail: info@wes.org

English Proficiency
The Johns Hopkins University requires students to have English proficiency for their courses of study. All international applicants must submit proof of their proficiency in English via the Test of English as a Foreign Language (TOEFL) or the International English Language Testing System (IELTS) before they can be offered admission.

A minimum score of 600 (paper-based), 250 (computer-based), or 100 (Internet-based) is required on the TOEFL; for the IELTS, an overall band score of at least 7.0 is required. The EP admissions office requires official copies of all results.

Requests to Change Program of Study
A student who wishes to change his/her status (e.g., from Special Student to master’s degree candidate) or field of study (e.g., from technical management to systems engineering, or from the general computer science program to the telecommunications and networking option) must submit a written request to the EP office. The student must meet all the admission requirements of the new program.

Registration
Before registering for any engineering classes, each student must apply as a degree or certificate candidate, or as a Special Student, and must submit appropriate application materials for review. Application procedures are found in the Admission Requirements (page 4). Applications are accepted on a continuing basis.

Payment of tuition is due at the specified deadline listed in the academic calendar. Payment may be made by check, credit card, tuition remission, or company contract accompanied by purchase order. EP does not defer payment for companies providing tuition reimbursement at the end of the term. In this instance, students must pay tuition themselves and be reimbursed by their employers. If payment is not made by the deadline date, a late payment fee of $150 will be incurred.

If you have registered and have not paid your balance, an e-mail statement with the balance due to the university will be sent to you on the 16th of each month. This is not a bill. This is a reminder of the debt owed to the university and is a reflection of your account status at the time of the e-mail. Changes in circumstances, for instance, adding or dropping courses, late registration, or late payment fees, may have an effect on the amount that you are responsible to pay.

Students are not permitted to register if there are unpaid bills from a previous term.

Course Schedule
The EP Course Schedule, which lists the day, time, location, and instructor for each course, is available on the web at ep.jhu.edu/schedule prior to each registration period. All students who have been enrolled in courses during the previous year will receive notification of the web posting of the Course Schedule. All relevant registration forms and deadlines can be found on the EP website.

Course Numbering System
All Whiting School of Engineering courses are numbered in the form 605:402, where

605 indicates the program—in this example, Computer Science
402 indicates the course number—in this example, Software Analysis and Design
Courses with a zero before the first decimal point—e.g., 600.439—are daytime offerings of the Whiting School departments.

Courses numbered xxx.1xx, xxx.2xx, and xxx.3xx are undergraduate level and will not count for graduate credit.

Course Credit
All courses 400-level and above earn 3 credit hours.

Web Registration
Advance registration takes place three times a year: prior to the fall semester, the spring semester, and the summer term.

All students are encouraged to use web registration. Web registration is available by logging onto ep.jhu.edu/register and following the appropriate link. Students must establish a JHED account in order to use web registration; instructions are available on the opening page.

Registering for Online Courses
Online course registration adheres to the same schedule as for on-site courses. Enrollment is granted on a first-come, first-served basis, and new and returning online students are strongly encouraged to register early. Online course enrollments are limited to 20 per section. Additional sections of online courses are added on the basis of student waitlists and instructor availability.

The deadline for adding online courses is a week after the first day of classes each term, which is earlier than the deadline for adding conventional courses. See the 2013–2014 Academic Calendar (page ii) for exact dates for each term.

Online course access information will be sent to your JHU e-mail account. All JHU students are required to activate their Outlook Live @ Hopkins e-mail account to receive all official communications, including class assignments, billing information, emergency notifications, and other important items. Directions to set up your account can be found at it.johnshopkins.edu/services/email/outlookliveathopkins.

Late Registration
Students may register after the beginning of a term if necessary. However, in order to attend a mandatory online orientation prior to the start of the term, students enrolling in their first EP online course must be registered no later than a week and a half prior to the first day of classes. The deadline for adding online courses is a week after the first day of classes each term, which is earlier than the deadline for conventional classes. Although there is no fee for late registration, students who delay registering may find course selection severely restricted. See the 2013–2014 Academic Calendar (page ii) for registration deadlines.

New Applicants
A new applicant may be approved to register for a class before a formal offer of admission is received. If the student is subsequently accepted to a degree or certificate program, the program committee will determine whether courses taken prior to admission may be counted in fulfillment of degree requirements. Please note that approval to take a course prior to receipt of an admission decision does not guarantee acceptance into the program. A student who has been granted approval to take a course before receiving an admissions decision must adhere to the published refund schedule. Refund exceptions will not be granted if the student is denied admission to the program.

Interdivisional Registration
With approval of their advisors, students may take courses in the full-time programs of the Whiting School or in other divisions of the university. Registration for these classes should be submitted by e-mail to ep.registration@jhu.edu. Please note that tuition rates vary by division.

Students in other divisions of Johns Hopkins may register for EP courses, subject to the regulations of their home divisions and availability of space.

Course Enrollment Limits
In order to foster high-quality faculty-student interaction, all courses have enrollment limits. Although every effort is made to offer additional sections of oversubscribed courses, this is not always possible.

Students may ask to be placed on waiting lists if their desired courses are filled, or they may indicate alternative course selections.

The university reserves the right to change instructors or to cancel any course with insufficient enrollment or for reasons beyond the control of the university.

Course Load
Students who are employed full-time are advised not to take more than two courses per term without written permission from their employer.

Auditors
Students may register as auditors with the approval of the appropriate program advisor. Although regular attendance is expected of auditors, they are exempt from quizzes, examinations, and other assigned work, and they receive no credit for the course. Students who are enrolled for credit but wish to become auditors must submit the “add/drop” form before the deadline listed for each term in the 2013–2014 Academic Calendar (page ii). There is no reduction in fees when auditing a course.

Adding and Dropping Courses
Courses may be added or dropped online at isis.jhu.edu. Deadlines for completing this procedure are given in the 2013–2014 Academic Calendar (page ii). Notification to the instructor does not constitute dropping a course. Students who stop attending a course without completing and submitting the drop form will receive an F grade. The
refund policy pertaining to dropped courses is described in Tuition and Fees (page 11).

Textbooks
For textbook information, visit ep.jhu.edu/textbooks.

Academic Regulations
Following are the general requirements governing study in the EP program at Johns Hopkins. Students are expected to be familiar with these requirements and with the specific regulations set forth in the sections relevant to particular programs of study.

Requirements for degree programs and certificate programs described in this catalog may change from time to time. When this occurs, students may fulfill either the requirements in force at the time of admission or those in force at the time of graduation.

Advisors and Program Planning
Students are assigned an advisor when accepted. In addition, students are strongly encouraged to contact their advisors prior to registration. Logging of course and program completion as well as viewing of approvals and exceptions approved by a student’s advisor can be tracked through Degree Audit viewable through ISIS.

Academic Standing
The university reserves the right to exclude at any time a student whose academic standing or general conduct is deemed unsatisfactory.

Master’s Degree Candidates
Only one grade of C may be counted toward the master’s degree.

Academic Probation—Any student receiving either one grade of F or two grades of C during their program of study will be placed on academic probation. Students placed on probation are permitted to retake any graduate course in which they have earned a grade of C or below. If a grade of B or above is earned in the repeated course, the probationary status will be removed. Please note that all courses are not offered every term. Students on probation who wish to retake a course will remain on probation until the course is offered again and completed with a grade of A or B. If an additional grade below B is received before the course is repeated and successfully completed, the student will be dismissed.

There are circumstances described below where students will not be placed on probation but will be immediately dismissed from the program.

Academic Dismissal—The following are causes for dismissal from the program:

• Students already on probation who receive an additional grade of C or below
• Students receiving a grade of C and a subsequent F
• Students receiving three grades of C
• Students receiving two grades of F
• Students receiving grades of F and C in the same term

Applicants who have been dismissed or suspended by any college or university, including Johns Hopkins, within the past four years are not eligible for admission.

Graduate Certificate or Advanced Certificate for Post-Master’s Study
No grade of C can be counted toward a graduate certificate or advanced certificate for post-master’s study. The above policy for probation and dismissal will apply.

Special Students
The above policy for probation and dismissal will apply.

Second Master’s Degree
After receiving a master’s degree from the programs, students may continue their graduate education in a second field if the appropriate prerequisites of the new program are fulfilled.

To receive a second master’s degree, all requirements for the second program must be satisfied. If the following conditions are met, up to two courses taken as part of the first degree may be applied toward requirements of the second:

• The course(s) must satisfy the requirements of the second degree
• The student’s advisor must approve the course(s) as appropriate to the plan of study
• The course(s) must fall within the five-year limit for the second degree; i.e., completion of the second degree must fall within five years from the date of the first class counted toward that degree

Time Limitation
To be counted toward the degree or certificate, all course work in the program must be completed within a specified period, which begins with the start of the first course in the student’s program:

• Master’s degree: 5 years
• Advanced Certificate: 3 years
• Graduate Certificate: 3 years

If necessary, a request for an extension, stating the extenuating circumstances, should be submitted in writing to the relevant program committee at least one semester before the student otherwise would be expected to graduate.

Leave of Absence
Students who do not plan to enroll in classes for a period of one year or more must notify the EP admissions office in writing and request a leave of absence for a specified period of time. The appropriate program chair will make the deci-
sion to approve or not approve the request. Students who are granted a leave of absence must resume their studies at the end of the allotted leave time. If warranted, the time permitted to complete degree requirements will be extended by the length of time granted for the leave of absence.

Students who do not resume their studies after a leave of absence has expired, or who have not enrolled for more than one year without having requested a leave of absence, will assume the status of a student who has withdrawn from the program. Such students must reapply and pay the $75 application fee and are subject to the admission requirements in force at the date of the new application. Acceptance is not guaranteed even for students previously admitted. Courses taken prior to the interruption of studies will not count toward requirements if they are not completed within the time allowed for degree completion.

**Transferability of Courses**

Courses successfully completed through Johns Hopkins EP may be transferred to other institutions. Transferability is solely at the discretion of the accepting institution.

**Transfer Courses**

Requests to transfer courses from another institution toward the master’s degree will be considered on an individual basis. A maximum of two courses may be accepted for transfer to a master’s degree or one course to a graduate or advanced certificate with prior approval of the appropriate program chair. No request will be considered for courses taken more than five years prior to the start of the program. Courses must be graduate level, not previously applied toward an awarded degree, and directly applicable to the student’s program of study at EP. Requests should be submitted in writing to the admissions office at the Dorsey Student Services Center. Please include a course description. An official transcript showing the course to be transferred is required. To be official, the transcript must be received by the admissions office at the Dorsey Student Services Center in an institution’s sealed envelope. Requests to transfer courses cannot be processed if the transcript is not official. The fee for transfer is $330 per course.

After being accepted into an EP program of study, students may not take classes at another institution for transfer back to their EP program. Courses successfully completed at EP may be accepted for transfer credit at other institutions, but such transferability is solely at the discretion of the accepting institution.

**Graduation**

Students who expect to receive a degree or certificate must submit an application for graduation. The graduation application should be submitted prior to the final term in which degree requirements will be completed. Instructions for completing the graduation application can be found by logging into ISIS and clicking on your program of study.

Students who are planning to graduate should complete all coursework on time and should not request to receive the grade of I (Incomplete) during their final semester.

Approximately two months after the semester begins, students who have submitted the application for graduation receive a preliminary letter stating that their names have been placed on the tentative graduation list for the semester in which they anticipate completing their degree requirements.

The WSE Graduate Committee meets three times each year to review candidates for graduation and to make recommendations to the university president for commencement. Students completing all requirements at the end of the summer term are reviewed by the committee in late October; those finishing at the end of the fall semester are reviewed in late February; and those finishing at the end of the spring semester are reviewed in May. After the WSE Graduate Committee meets, students on the graduation list receive a letter confirming the committee’s action. Degrees are conferred three times a year, after spring, summer, and fall semesters.

Commencement information is sent the first week in March. To receive their diploma, students must pay all student accounts in full and resolve all outstanding charges of misconduct and violations of academic integrity. Students will receive an e-bill notification in the spring from Student Accounts. The e-bill will be sent to the student’s preferred e-mail account. For graduation fees, see Tuition and Fees (page 11).

Johns Hopkins University diplomas indicate the school (e.g., Whiting School of Engineering), degree, and major (e.g., Master of Science-Computer Science) without identifying the student’s concentration or option.

**Honors**

EP students will graduate with honors if they have earned an A+, A, or A– in all courses taken between admission and graduation from the degree program. Any other grade except a withdrawal or audit will disqualify students from receiving honors. The designation “Honors” will appear on student transcripts.

**Grading System**

The following grades are used for the courses: A+, A, A– (excellent), B+, B, B– (good), C (unsatisfactory), F (failure), I (incomplete), W (official withdrawal), and AU (audit). The last two are not assigned by instructors.

A grade of F indicates the student’s failure to complete or comprehend the course work. A course for which an unsatisfactory grade (C or F) has been received may be retaken. The original grade is replaced with an R. If the failed course includes laboratory, both the lecture and laboratory work must be retaken unless the instructor indicates otherwise. A grade of W is issued to those who have dropped the course after the refund period (the sixth class meeting for on-site courses) but before the drop deadline.
The transcript is part of the student’s permanent record at the university. No grade may be changed except to correct an error, to replace an incomplete with a grade, or to replace a grade with an R.

The Whiting School assumes that students possess acceptable written command of the English language. It is proper for faculty to consider writing quality when assigning grades.

**Incompletes**
A grade of Incomplete (I) is assigned when a student fails to complete a course on time for valid reasons, usually under circumstances beyond his or her control. A $60 change of grade fee must be mailed to the EP Dorsey Student Services Center office before the final grade will be posted on the student’s transcript (except for grades of F).

Conditions for resolving an incomplete are established by the instructor. A final grade must be submitted to the Registrar within four weeks after the start of the following term. A grade of F will be assigned if the incomplete work is not submitted by the deadline. For academic year 2013-2014, the dates by which final grades for incomplete work must be resolved are:

- Summer term: September 28
- Fall semester: February 22
- Spring semester: June 28

Students who expect to complete degree requirements but have an incomplete are not certified for graduation until the end of the following term.

**Grade Reports**
At the midpoint of each term, instructors are requested to provide a list of students whose work at that time is unsatisfactory. Students are notified by the EP Student Services staff if their names are reported so they can take corrective action. These early reports are for the benefit of students and their advisors and are not part of the permanent record.

Grades are available online at isis.jhu.edu/sswf. These reports cannot be requested by telephone or personal inquiry. Students with questions regarding their grade reports or who want their transcripts sent to other institutions should make arrangements with the Office of the Registrar, 410-516-7088 or jhu.edu/registrar.

**Grade Appeals**
A student’s concerns regarding grades must be first discussed thoroughly with his or her instructor. If the student and the instructor are unable to reach agreement, the student may appeal, in writing, the instructor’s decision to the appropriate program chair, and, finally, to the associate dean. At each review level, evaluation criteria will be limited to: (1) verification that there was not an error in recording the grade and (2) verification that the grade was determined on the basis of considered academic judgment. Grade appeals must be initiated within one semester after completing the course in question.

**Student Attendance**
Students are expected to regularly attend all courses in which they are enrolled. Although EP and the university have no specific rules governing absences, the course instructor may announce certain attendance requirements. It is the student’s responsibility to be aware of those requirements. Students who know they will be absent from class, especially for an extended period of time, should notify the instructor as far in advance as possible. It is the student’s responsibility to discuss missed assignments and exams with the instructor. If an instructor is unavoidably late for class, the site office will attempt to notify students and tell them to wait, if it is practical. If an instructor is unable to meet a class, every attempt will be made by EP staff to inform students of the cancellation, a makeup time for the class (if available), and information regarding assignments. If an instructor informs the EP office of a class cancellation with enough lead time, phone calls will be made to students.

**Academic Misconduct**
This section summarizes the policy on academic misconduct described at engineering.jhu.edu/include/content/pdf-word/misconduct-policy.pdf

**The Roles of Students and Faculty**
Johns Hopkins faculty and students have a joint responsibility to maintain the academic integrity of the university in all respects. Students must conduct themselves in a manner appropriate to the university’s mission as an institution of higher education. Students are obligated to refrain from acts that they know, or under the circumstances have reason to know, impair the academic integrity of the university. Violations of academic integrity include, but are not limited to, cheating; plagiarism; unapproved multiple submissions; knowingly furnishing false information to any agent of the university for inclusion in academic records; and falsification, forgery, alteration, destruction, or misuse of official university documents. Members of the faculty are responsible for announcing the academic requirements of each course, for the conduct of examinations, and for the security of examination papers and teaching laboratories. It is the duty of faculty to report suspected violations of academic integrity to the appropriate program chair. It is the responsibility of each student to report to the instructor any suspected violations of academic integrity.

**Violations of Academic Integrity**
After reviewing the circumstances of any suspected violation of academic integrity to determine if a violation may have occurred, a program chair will promptly report (in writing) the suspected violation to the associate dean. Supporting evidence (e.g., copies of examination papers) should accompany the report. The associate dean will resolve the issues following the procedures set forth on the website noted above.
**Copyright Violations**

Copying, downloading, or distributing music, videos, software, games, or other copyrighted materials without permission of the owner violates both federal law and university policy and will be submitted for disciplinary action.

Original works fixed in any tangible medium of expression, which includes storage within computers, are copyrighted to the author from the moment of creation. No notice of copyright is required. Except under limited circumstances for limited purposes, you may not make or distribute copies of material belonging to others without their permission. Unless a site specifically grants you permission to download and copy material from the site, you should assume that you cannot do so. You should also assume that all person-to-person sharing of music, programs, videos, and software is a violation of copyright. Copyright violations will be submitted for disciplinary action.

**Computer Usage**

Because Johns Hopkins University Office of Information Technology updates its policies frequently, please visit the JHU IT website at it.jhu.edu for the latest information on usage and security. The following includes key elements of the policy, which is posted in all EP computer labs.

Acceptable use of IT resources is use that is consistent with Johns Hopkins’ missions of education, research, service, and patient care and is legal, ethical, and honest; it must respect intellectual property, ownership of data, system security mechanisms, and individuals’ rights to privacy and freedom from intimidation, harassment, and annoyance; it must show consideration in the consumption and utilization of IT resources; and it must not jeopardize Johns Hopkins’ not-for-profit status. Incidental personal use of IT resources is permitted if consistent with applicable Johns Hopkins University and divisional policy, and if such use is reasonable, not excessive, and does not impair work performance or productivity.

Please visit the JHU IT link above for additional information on unacceptable use of IT resources.

**Tuition and Fees**

Students whose tuition is paid by contract should begin processing requests with their employers well before registration deadlines to ensure that payment is made as required. Students are ultimately responsible for all costs associated with their registration.

**Tuition**

The graduate tuition fee is $3,330 per course, unless otherwise noted. The tuition for 200-level courses is $1,830. Tuition for courses in the daytime programs of the Whiting School is a percentage of full-time tuition. If students need a receipt for the classes they are attending, they may contact Student Accounts at 410-516-8158.

**Application Fee**

The application fee for degree and certificate programs and Special Students is $75. This fee must be submitted with the application and is not refundable under any circumstances. Whiting School of Engineering degree and certificate recipients who wish to enter into another degree or certificate program may apply without paying an application fee.

**Graduation Fee**

The graduation fee is $100 and is payable upon receipt of an e-bill notification from the office of Student Accounts.

**Late Tuition Payment Fee**

Tuition payment due dates are indicated in the 2013–2014 Academic Calendar (page ii). If payment is received after the due date, a late payment fee of $150 will be incurred.

**Transfer Credit Fee**

Graduate courses completed at another school and approved for transfer are assessed a fee of $330 per course.

**Fee for Removal of an Incomplete Grade**

Students who receive an incomplete grade for a course are required to pay a $60 fee to have the I grade changed to the final grade. This fee must be paid to the EP office, Dorsey Student Services Center, before the grade change can be released by the Registrar. No payment is required if the final grade is an F.

**Refund Policy**

Refunds apply only to the tuition portion of a student’s charges and are calculated from the date of drop submission. Telephone drops or withdrawals are not accepted. Refunds are not applicable to any fees. Refunds are not granted to students who have been suspended or dismissed for disciplinary reasons. Tuition refunds are made in accordance with the schedule below.

### Refund Schedule

**On-site Courses**

<table>
<thead>
<tr>
<th>Drop Date</th>
<th>Refund</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to fourth class meeting</td>
<td>75%</td>
</tr>
<tr>
<td>Prior to fifth class meeting</td>
<td>50%</td>
</tr>
<tr>
<td>Prior to sixth class meeting</td>
<td>25%</td>
</tr>
</tbody>
</table>

**Online Courses**

<table>
<thead>
<tr>
<th>Drop Date</th>
<th>Refund</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to third week</td>
<td>100%</td>
</tr>
<tr>
<td>Prior to fourth week</td>
<td>75%</td>
</tr>
<tr>
<td>Prior to fifth week</td>
<td>50%</td>
</tr>
<tr>
<td>Prior to sixth week</td>
<td>25%</td>
</tr>
</tbody>
</table>

Students who are enrolled at The Johns Hopkins University for the first time and who are receiving federal student finan-
Financial Aid

Federal financial aid in the form of student loans is available to part-time graduate degree candidates who are enrolled in two or more courses per term. Students must complete the Free Application for Federal Student Aid (FAFSA). This form is available online at fafs.ed.gov. For more information about applying for financial aid, please review the Office of Student Financial Services website at jhu.edu/finaid or contact the Office of Student Financial Services, 146 Garland Hall, 410-516-8028, or fin_aid@jhu.edu.

Definition of Full-Time, Half-Time, and Part-Time Enrollment

Students who take three or more EP courses each term are considered to be enrolled on a full-time basis, students who take two courses are considered to be enrolled on a half-time basis, and students who take one course are considered to be enrolled on a part-time basis.

Veterans Benefits

Johns Hopkins is approved by the Maryland Higher Education Commission for the training of veterans and the widows and children of deceased veterans under provisions of the various federal laws pertaining to veterans’ educational benefits. Information about veterans’ benefits and enrollment procedures may be obtained at the Registrar’s Office, Garland Hall, 410-516-7071. Students eligible for veterans educational benefits register and pay their university bills in the same manner as other students. Reimbursement is made by the Department of Veterans Affairs on a monthly basis. The amount of reimbursement is determined by the veteran’s number of dependents and course load.

Note that credits are not assigned to EP graduate courses. A statement of “equivalent” credits for each graduate course taken may be obtained from the Registrar’s Office. To obtain reimbursement, a veteran must comply with the following procedures:

Initial Enrollment—The veteran must first apply and be admitted to one of the schools of the university. He or she then obtains an Application for Program of Education or Training (DVA Form 22-1990) from the U.S. Department of Veterans Affairs at gibill.va.gov.

After completing the application, the veteran sends it, with a certified copy of appropriate discharge papers, to the following address:

Johns Hopkins University
Office of the Registrar - 75 Garland Hall
Veterans Affairs
3400 N. Charles Street
Baltimore, Maryland 21218-2681

Facilities and Student Services

EP courses are offered throughout Maryland at the Homewood campus in Baltimore; the Applied Physics Laboratory (APL) in Laurel; the Montgomery County Campus in Rockville; the Dorsey Student Services Center near Baltimore/Washington International Thurgood Marshall Airport; the Southern Maryland Higher Education Center in St. Mary's County; the Washington Center in Washington, DC; the Higher Education and Conference Center @ HEAT in Harford County; the Crystal City Center in Arlington, Virginia; and fully online. The educational and student facilities and...
services provided at each location are described on the following pages.

**Student ID JCards**
University identification cards are mailed to the home address of every registered student. The JCard acts as the university library card, which enables students to check out books from the Homewood Eisenhower Library or at any of the campus center libraries and provides access to many computer laboratories. To replace a lost or stolen JCard, contact the JCard Office at 410-516-5121.

**Transcripts**
Official transcripts will be mailed at no charge on written request of the student. Requests for transcripts should be directed to the Office of the Registrar, 410-516-7088. Transcripts may also be ordered online, for a fee, from studentclearinghouse.org. For more information about each of these options, see web.jhu.edu/registrar/transcripts.

**International Student Services**
For a description of all the services available at Johns Hopkins for international students, contact the Office of International Student and Scholar Services at 410-516-1013 or jhu.edu/iss. For information related to EP admission, please refer to Admission Requirements (page 4).

**Services for Students with Disabilities**
The Johns Hopkins University is committed to making all academic programs, support services, and facilities accessible to qualified individuals. Students with disabilities who require reasonable accommodations should contact the EP Disability Support Services Coordinator at 410-516-2306 or e-mail jhep@jhu.edu.

To receive accommodations, students must provide the university a comprehensive evaluation of a specific disability from a qualified diagnostician that identifies the type of disability, describes the current level of functioning in an academic setting, and lists recommended accommodations. All documentation will be reviewed, and reasonable accommodations will be provided based on the student's needs. Students are required to contact the EP office at least six weeks prior to the beginning of each semester to ensure that services will be available.

For questions or concerns regarding university-wide disability issues, please e-mail studentdisabilityservices@jhu.edu.

**JH Student Assistance Program**
The JH Student Assistance Program (JHSAP) is a professional counseling service that can assist students with managing problems of daily living. Stress, personal problems, family conflict, and life challenges can affect the academic progress of students. JHSAP focuses on problem-solving through short-term counseling. Accessing the service is simple and requires only a phone call to arrange an appointment with a counselor. To meet the needs of our students, offices are conveniently located in the Washington/Baltimore corridor. Online students may call one of the numbers below for consultation and will be directed to the appropriate resource or office. To contact JHSAP, call 443-997-7000 or toll-free 866-764-2317. Additional information regarding the JHSAP services can be obtained at jhsap.org. JHSAP services are completely confidential. The program operates under State and Federal confidentiality legislation and is HIPAA compliant.

**Inclement Weather**
The JHU Weather Emergency Line can be reached at 410-516-7781 or 800-548-9004. The JHU Weather Emergency Line provides information on campus closings due to inclement weather. The university may also use the same phone lines occasionally to distribute other urgent information. Announcements and closings will also be posted on the website at webapps.jhu.edu/emergencynotices.

**Web-Based Student Directory**
JHED (Johns Hopkins Enterprise Directory) is the primary source for contact information of Johns Hopkins students. Your JHED login ID will be used for many web-based services, such as online registration, remote library access, and some course websites. You may find your login ID and initialize your account by going to my.jhu.edu from a computer at any of the campuses or by calling 410-516-HELP. Once you have set a password, you may use JHED from anywhere by logging in. If you have any questions, contact Hopkins Information Technology Services at 410-516-HELP.

**Computers**
IT@Johns Hopkins (IT@JH) provides a number of resources that are useful to students. Brief descriptions are provided below. For more information, go to jumpstart.jhu.edu.

**Outlook Live @ Hopkins**—LoginID@live.johnshopkins.edu provides JHU students with a free 10GB lifetime e-mail account, a 25GB online storage solution, collaboration, blogging, photo sharing, event planning, instant messaging tools, and more. Some features of Outlook Live @ Hopkins include:

- Built-in protection and anytime/anywhere access
- A 10GB e-mail account built on Outlook Live, permitting up to 20MB attachments
- Easy access to e-mail from a variety of browsers on both the PC and Mac, including full support for Internet Explorer, Firefox, and Safari
- Connection to mailboxes using POP3, IMAP4 with preferred e-mail program or mobile phones
- Capabilities such as address books, calendaring, mobile push e-mail, instant messaging, and more
- Improved collaboration and productivity, with ease of finding and sharing data and schedules from anywhere
- Ability to look up other users in the address book

**Facilities and Student Services**

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**JCard Office**
Computer laboratories. To replace a lost or stolen JCard, contact the JCard Office at 410-516-5121.

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- Connection to mailboxes using POP3, IMAP4 with preferred e-mail program or mobile phones
- Capabilities such as address books, calendaring, mobile push e-mail, instant messaging, and more
- Improved collaboration and productivity, with ease of finding and sharing data and schedules from anywhere
- Ability to look up other users in the address book

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**Facilities and Student Services**

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A single inbox to access all important communications

All students are required to activate their assigned Outlook Live e-mail address. All official communications from EP and Johns Hopkins University will be sent to this address, including class assignments, billing information, emergency notifications, and other important items. Visit it.johnshopkins.edu/services/email/outlookliveathopkins to find instructions to activate your Outlook Live e-mail address and to forward your JHU e-mail to other addresses.

JShare—JShare is a web-based utility intended to provide students with a personal, easy-to-use interface to upload, download, and share files to users both inside and outside of the institution. Some features of JShare include, but are not limited to:

- 5GB of file storage space for students and staff
- Secure file access from anywhere at any time
- Advanced collaboration and document management
- File sharing ability both inside and outside the institution
- Ability to e-mail files as links to reduce the load on e-mail systems
- Ability to create and maintain personal websites

Visit it.johnshopkins.edu/services/collaboration_tools/jshare for more information.

JHConnect—JHConnect is a remote access application that provides access to restricted Hopkins applications and systems when you are not on campus. JHConnect offers greater compatibility and support for newer computers and their operating systems. Remote access to Hopkins is provided by JHConnect online through the myJH portal. More information about JHConnect is available at portalcontent.johnshopkins.edu/sslvpn/JHConnect-FAQ.html.

Note: You must have an active JHED login to access this site.

Anti-Virus Policy—All devices vulnerable to electronic viruses must be appropriately safeguarded against infection and retransmission. It is the responsibility of every user to ensure that anti-virus protection is current and effectively implemented. Infected devices may be blocked, removed, or both from the JH Network by IT@JH or appropriate departmental personnel.

On behalf of the Johns Hopkins Institutions, IT@JH has licensed Symantec AntiVirus, available for Windows and Mac OS X operating systems.

Johns Hopkins students may go to it.jhu.edu/antivirus to download and use Symantec AntiVirus on computers owned by the university or health system or on personally owned computers, as long as they remain part of the Johns Hopkins community. Personal use of the software must cease when the student leaves the university or health system.

Download access is restricted to those with a valid JHED (Johns Hopkins Enterprise Directory) LID (login ID) and password.

Questions and Grievances

If you have a question or grievance that you would like to communicate to EP, please e-mail jhep@jhu.edu.

The Homewood Campus

The Homewood campus, located at 3400 North Charles Street in Baltimore, is grouped around two adjoining quadrangles. The Georgian architecture and wooded walkways and lawns make Homewood a pleasant retreat in a residential area of Baltimore.

Libraries

The entire library collection of the Johns Hopkins University contains close to three million volumes; more than two million of these and one million microforms are available on the Homewood campus. Most of the Homewood collections are shelved in the Milton S. Eisenhower Library, which is open until 10 p.m. on Friday and Saturday and until midnight on the other days of the week.

After registering, students are issued a JCard by the JCard Office. This card entitles them to use the Eisenhower Library and the Hutzler Reading Room, and hours of operation can be found at library.jhu.edu/about/hours.html.

Textbooks

EP has selected MBS Direct as its single online textbook provider for all locations. MBS Direct also provides used books, buyback, a return policy, and a secure ordering site. Course textbooks can be found at ep.jhu.edu/textbooks or by clicking on the textbook icon for each individual course on the Course Schedule on the EP website.

Johns Hopkins Merchandise

Barnes & Noble Johns Hopkins sells apparel, gifts, school supplies, and books. For more information, call 410-662-5850 or visit johns-hopkins.bncollege.com.

Hopkins Student Union

Located in Levering Hall and the Glass Pavilion, the Hopkins Student Union offers various programs and activities for students, faculty, staff, and friends of the university. Levering Hall contains the Levering Food Court, a complete dining facility with various retail venues offering a combination of American and ethnic fare, and the Pura Vida Organic Coffee shop located in the Levering Lobby, offering gourmet coffee, sandwiches, and pastries. The hours of operation for all Homewood dining facilities are available at jhu.edu/hds/dining.

Security Services

A daily escort van service is available during the evening hours (5 p.m. to 3 a.m.) to pick up and deliver students
to any campus parking lot or other location within a one-mile radius of campus. Vans leave every half hour from the Eisenhower Library.

Walking escorts are available by calling extension 8700 from any campus phone or 410-516-8700 from an outside or public telephone. Push-button security/escort phones, located in several campus buildings, can be used to alert security officers of an emergency, to request information, or to summon the escort van.

Emergency telephone stands with blue lights, which connect directly with the security office, are located at strategic locations around campus. These telephones open a direct line to the security office as soon as the receiver is lifted or the button pushed. To ward off a possible attacker, an alarm sounds at the phone. Pay telephones also are available in most campus buildings. Security officers also patrol parking lots from 3 to 11 p.m., Monday through Friday. Student monitors, wearing bright orange vests and carrying radios, patrol the upper and lower quads during fall and spring semesters.

To reach the security office, call 410-516-4600. In the case of an emergency, call 410-516-7777.

Parking
Parking arrangements are made in the South Garage, under the Decker Quadrangle. Parking office hours are Monday through Friday, 7:30 a.m. to 10:00 p.m., and Saturday through Sunday, 10:00 a.m. to 6:30 p.m. 410-516-7275.

Applied Physics Laboratory Education Center
The Applied Physics Laboratory (APL), a division of the Johns Hopkins University, is primarily a research and development organization. As such, a major part of its mission is the application of advanced science and technology in solving problems of national and global significance. However, its mission also includes support of the educational programs of the university, and the Laboratory maintains strong academic relationships with the other university divisions.

One of APL’s most significant educational contributions is its close collaboration with the EP program. Chairs for eight of EP’s 15 programs hold staff positions at APL, along with nearly half of EP’s instructors. APL provides classrooms, conference space, computer labs, and UNIX servers for administrative and academic support of EP in the Kossiakoff Center, as well as classrooms in the R. E. Gibson Library.

Computers
Computer facilities at the Kossiakoff Center include Multi-User UNIX systems (two Sun servers) and a Sun Ray appliance-based X-terminals lab that provides a windowing environment via the default CDE window manager or the gnome window manager. These terminals are connected to the UNIX servers as well as to the Internet via a high-speed LAN or WAN. Personal computer labs provide support for general purpose computing and applications development, embedded/interface design (with scopes and embedded processor development systems), and computer/network security. Remote access to the servers at APL is also available.

Parking
Parking tags are not required. The lower level parking lot near the Kossiakoff Center is recommended.

Montgomery County Campus
The mission of the Montgomery County Campus (MCC) in the Shady Grove Life Sciences Center in Rockville is to create a community of education, business, and government organizations where collaborative thinking and scientific discovery advance academic and economic development. The campus, which houses 46 smart classrooms and five computer labs, a full-service library, café, and extensive conference space, welcomes 4,000 students per year. Four of the university’s nine schools offer more than 60 degree and certificate programs at this location. In recent years, three technology research centers have co-located with Johns Hopkins University on this campus.

Library
The Montgomery County Campus Library maintains a reference and circulating collection of materials for use by faculty and students. Subject areas in the collection include computer science, electrical engineering, environmental engineering and science, management, and physics. Interlibrary loan service is provided to assist in obtaining journals and books that are not available at the MCC library. An online catalog of the collection and a variety of full-text INSPEC and IEEE databases, including Compendex, are accessible through personal computer workstations in the library.

To use materials, present your JCard at the circulation desk. The library is open from noon to 9 p.m. on Monday through Thursday, noon to 6 p.m. on Friday, and 10:00 a.m. to 5 p.m. on Saturday.

Computers
Computer facilities at MCC include Sun Ray thin clients, UNIX servers and workstations, as well as personal computers available for student use. In addition, students have access via high-speed data links to UNIX servers at Homewood and APL. Dial-in PPP access to the servers is also available. A fully functional networking lab with seven routers and three switches that are accessible locally and via a console server over the Internet is also located at MCC.

Café
Located in the Academic and Research building, the café serves snacks and sandwiches during the daytime and early evening hours.
Parking
Free parking permits are issued on completion of the application form. Parking permits may be obtained at the Gilchrist Hall front desk during the first two weeks of classes. There is no charge for this service.

Dorsey Student Services Center
In addition to classrooms and computer labs, the Dorsey Center houses the admissions and registration staff and serves as a central point of access for academic advising and financial services. The Dorsey Center is located near the Baltimore/Washington International Thurgood Marshall Airport at 6810 Deerpath Road, Suite 100, Elkridge, MD.

The center has an instructional laboratory equipped with Sun Ray thin client workstations, personal computers, and high-speed Internet access. Access to the UNIX servers at APL is provided via dedicated high-speed lines. The Dorsey Center houses the Computer Robotics Lab, which allows students to develop computer-controlled autonomous robots. The center is also the site of the EP’s Microwave Engineering Laboratory, a state-of-the-art facility for designing, developing, and testing microwave chips and circuits. This laboratory houses a full variety of microwave testing and measurement equipment including:

- Network analyzers
- Spectrum analyzers
- Noise measuring equipment
- Sweep generators
- Synthesizers
- Fabrication and assembly equipment

In support of the microwave chip and circuit design process, our CAD laboratory has 13 workstations (12 for students and one for the instructor) offering the latest versions of following software:

- Pro/ENGINEER and Pro/a list for mechanical engineering and analysis
- Agilent ADS, Sonnet, MATLAB, and gEE-CAD for microwave chip and circuit design and analysis
- CAD Capture and Layout for PCB design

These two laboratories offer our students the latest in hardware and software technology available in industry today.

Southern Maryland Higher Education Center
This facility was created by the Maryland General Assembly to serve as the regional upper-level undergraduate and graduate education and research institution for Southern Maryland. Currently, 14 colleges and universities are participating, offering more than 95 academic programs, with more than 80 graduate and 15 undergraduate completion programs. Facilities include two buildings with classrooms, a large multipurpose room, computer labs, a conference hall, a learning conference room, two student lounges, vending areas, and interactive videoconferencing capability. The full EP Systems Engineering and Technical Management programs are offered here, along with selected courses in Applied and Computational Mathematics.

Washington, DC, Center
The Washington Center is conveniently located near the Dupont Circle Metro stop. Selected courses in environmental engineering, science, and management are currently being offered on site.

Crystal City Center
The Crystal City Center is EP’s first Northern Virginia center, located just south of the Pentagon and accessible via Metro’s blue and yellow lines. Selected courses in systems engineering are currently offered on site. The Johns Hopkins University Whiting School of Engineering is certified to operate in the Commonwealth of Virginia by the State Council of Higher Education for Virginia.

Higher Education and Conference Center @ HEAT
The HEAT Center is located in Harford County. Selected courses in environmental engineering, science, and management; applied and computational mathematics; and systems engineering are currently being offered on-site.

Intersite Links
To increase the variety of courses at the centers, select courses are offered using video-teleconferencing equipment. This technology allows for two-way audio and video connectivity, creating real-time interaction between the sending and receiving sites. The system provides links between APL, the Dorsey Center, the Southern Maryland Higher Education Center, and the Montgomery County Campus and permits students at any of the sites to enroll at courses originating at the other.

To further facilitate communication, high-speed data links connect Homewood, APL, the Montgomery County Campus, and the Dorsey Center, enabling students to access systems internally and via the Internet.
Applied and Computational Mathematics

Applied and computational mathematics is concerned with the use of mathematics to solve problems in diverse areas such as engineering, business, science, health care, information technology, and public policy. There is a strong connection between applied mathematics and modern computational methods, especially in the design and computer implementation of mathematical algorithms.

The Master of Science in Applied and Computational Mathematics (ACM) program prepares students for work in their areas of interest through instruction in mathematical and computational techniques of fundamental importance and practical relevance. The program allows students to choose an area of concentration such as probability and statistics, applied analysis, operations research, information technology and computation, or simulation and modeling. Students are also free to select courses from different areas to meet their individual needs. All students in the program will take a blend of introductory and advanced courses. Modern computing facilities are available for student use at the Kossiakoff Center of the Applied Physics Laboratory and all other EP campuses. Some courses are offered online.

Program Committee

James C. Spall, Program Chair
Principal Professional Staff
Applied Physics Laboratory

Beryl Castello
Senior Lecturer, Applied Mathematics and Statistics
Whiting School of Engineering

Stacy D. Hill
Senior Professional Staff
Applied Physics Laboratory

George Nakos
Professor, Mathematics
U.S. Naval Academy

Edward R. Scheinerman
Professor, Applied Mathematics and Statistics
Vice Dean for Education
Whiting School of Engineering

J. Miller Whisnant
Principal Professional Staff
Applied Physics Laboratory

Admission Requirements

MS Degree or Special Student. Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements (page 4). The applicant’s prior education must include at least one mathematics course beyond multivariate calculus (such as advanced calculus, differential equations, or linear algebra). All applicants must be familiar with at least one programming language (e.g., C, C++, FORTRAN, Java, Python, or MATLAB).

Advanced Certificate for Post-Master’s Study. Applicants must meet the criteria above and hold at least a master's degree in applied and computational mathematics or a closely related area. It is expected that the applicant will have completed courses equivalent to 625.403 Statistical Methods and Data Analysis and at least one of 625.401 Real Analysis or 625.409 Matrix Theory in prior graduate coursework.

Course Requirements

MS Degree. Ten one-term courses must be completed within five years. The 10 courses must include 625.403 (Statistical Methods and Data Analysis); at least one of 625.401 (Real Analysis) or 625.409 (Matrix Theory); and at least one of the two-term sequences 625.717/718 (Advanced Differential Equations: Partial and Nonlinear Differential Equations), 625.721/722 (Probability and Stochastic Processes I and II), or 625.725/726 (Theory of Statistics I and II). The remaining six courses must include at least four from the ACM program (courses numbered 625.xxx), with at least two of the four courses at the 700 level. Students are required to take at least one 700-level course outside of the sequences 625.717/718, 625.721/722, and 625.725/726. A student who has taken at least one year of undergraduate statistics or one semester of graduate statistics (outside of ACM) may substitute another 625.xxx course for 625.403 with approval of the student’s advisor. Two one-term elective courses are also to be taken. These may be from the ACM program or from another graduate program described in this catalog, subject to the approval of the student’s advisor. If chosen from another program, the courses are required to have significant mathematical content. A thesis or knowledge of a foreign language is not required.

Advanced Certificate for Post-Master’s Study. Six one-term courses must be completed within three years. At least four of the six courses must be ACM courses numbered 625.480 or higher, with at least three of these courses being at the 700 level. Courses 625.401 (Real Analysis), 625.403 (Statistical Methods and Data Analysis), and 625.409 (Matrix Theory) may not be counted toward the post-master’s certificate. At least one of the 700-level courses must be outside of the sequences 625.717/718, 625.721/722, and 625.725/726. Students are allowed to take one mathematically oriented elective course from outside the ACM program as part of the six courses for the certificate, subject to advisor approval.

A student with a long-standing interest in pursuing a PhD through the Applied Mathematics and Statistics (AMS) Department at the Homewood campus should coordinate his/her course plan with an ACM advisor and with a representative in the AMS Department. Certain courses within ACM
may be especially helpful in passing the required entrance examination for the PhD program. No priority of admission for the PhD degree program is given to graduates of the ACM program.

Listed below are five concentration areas within applied and computational mathematics. Students are free to focus their course selections in one of these areas. There is no requirement that a concentration area be chosen.

### I. Probability and Statistics

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>625.403</td>
<td>Statistical Methods and Data Analysis</td>
</tr>
<tr>
<td>625.417</td>
<td>Applied Combinatorics and Discrete Mathematics</td>
</tr>
<tr>
<td>625.420</td>
<td>Mathematical Methods for Signal Processing</td>
</tr>
<tr>
<td>625.423</td>
<td>Introduction to Operations Research: Probabilistic Models</td>
</tr>
<tr>
<td>625.438</td>
<td>Neural Networks</td>
</tr>
<tr>
<td>625.441</td>
<td>Mathematics of Finance</td>
</tr>
<tr>
<td>625.442</td>
<td>Mathematics of Risk, Options, and Financial Derivatives</td>
</tr>
<tr>
<td>625.461</td>
<td>Linear Models and Regression</td>
</tr>
<tr>
<td>625.462</td>
<td>Design and Analysis of Experiments</td>
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<tr>
<td>625.463</td>
<td>Multivariate Statistics and Stochastic Analysis</td>
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<tr>
<td>625.464</td>
<td>Computational Statistics</td>
</tr>
<tr>
<td>625.480</td>
<td>Cryptography</td>
</tr>
<tr>
<td>625.490</td>
<td>Computational Complexity and Approximation</td>
</tr>
<tr>
<td>625.495</td>
<td>Time Series Analysis and Dynamic Modeling</td>
</tr>
<tr>
<td>625.710</td>
<td>Fourier Analysis with Applications to Signal Processing and Differential Equations</td>
</tr>
<tr>
<td>625.714</td>
<td>Introductory Stochastic Differential Equations with Applications</td>
</tr>
<tr>
<td>625.721</td>
<td>Probability and Stochastic Process I</td>
</tr>
<tr>
<td>625.722</td>
<td>Probability and Stochastic Process II</td>
</tr>
<tr>
<td>625.725</td>
<td>Theory of Statistics I</td>
</tr>
<tr>
<td>625.726</td>
<td>Theory of Statistics II</td>
</tr>
<tr>
<td>625.728</td>
<td>Measure-Theoretic Probability</td>
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<tr>
<td>625.734</td>
<td>Queuing Theory with Applications to Computer Science</td>
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<tr>
<td>625.740</td>
<td>Data Mining</td>
</tr>
<tr>
<td>625.741</td>
<td>Game Theory</td>
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<tr>
<td>625.743</td>
<td>Stochastic Optimization and Control</td>
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<tr>
<td>625.744</td>
<td>Modeling, Simulation, and Monte Carlo</td>
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</table>

### II. Applied Analysis

<table>
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<tr>
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<tbody>
<tr>
<td>625.401</td>
<td>Real Analysis</td>
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<tr>
<td>625.402</td>
<td>Modern Algebra</td>
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<tr>
<td>625.404</td>
<td>Ordinary Differential Equations</td>
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<tr>
<td>625.409</td>
<td>Matrix Theory</td>
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<tr>
<td>625.411</td>
<td>Computational Methods</td>
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<tr>
<td>625.480</td>
<td>Cryptography</td>
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### III. Operations Research

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<td>Matrix Theory</td>
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<tr>
<td>625.414</td>
<td>Linear Optimization</td>
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<td>625.415</td>
<td>Nonlinear Optimization</td>
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<td>625.417</td>
<td>Applied Combinatorics and Discrete Mathematics</td>
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<td>625.423</td>
<td>Introduction to Operations Research: Probabilistic Models</td>
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<td>625.436</td>
<td>Graph Theory</td>
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<td>Multivariate Statistics and Stochastic Analysis</td>
</tr>
<tr>
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### IV. Information Technology and Computation

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The above non-graduate courses have the following characteristics and relationship to one another:

- **625.201** is a broad review of calculus, linear algebra, and ordinary differential equations.
- **625.250** is a deeper review of multivariate calculus and linear algebra, including complex variables, but the course does not cover differential equations (this course may count as a replacement for multivariate calculus for those students lacking the required undergraduate multivariate calculus course).
- **625.251** covers ordinary and partial differential equations and is especially oriented to providing the mathematics background for the Applied Physics program and some tracks in the Electrical and Computer Engineering program.
- **625.260** on linear systems is designed primarily for students with an interest in the theory, transforms, and algorithms associated with linear differential equations.
625.201  General Applied Mathematics
This course is designed for students whose prior background does not fully satisfy the mathematics requirements for admission and/or for students who wish to take a refresher course in applied mathematics. The course provides a review of differential and integral calculus in one or more variables. It covers elementary linear algebra and differential equations, including first- and second-order linear differential equations. Basic concepts of matrix theory are discussed (e.g., matrix multiplication, inversion, and eigenvalues/eigenvectors).

Prerequisites
Two semesters of calculus.

Course Notes
Not for graduate credit. This course alone does not fulfill the mathematics requirements for admission to the Applied and Computational Mathematics program; additional course work is required.

Instructor: Davis

625.250  Applied Mathematics I
This course covers the fundamental mathematical tools required in applied physics and engineering. The goal is to present students with the mathematical techniques used in engineering and scientific analysis and to demonstrate these techniques by the solution of relevant problems in various disciplines. Areas include vector analysis, linear algebra, matrix theory, and complex variables.

Prerequisites
Differential and integral calculus.

Course Notes
Not for graduate credit.

Instructor: D'Arghangelo

625.251  Applied Mathematics II
This course is a companion to 625.250. Topics include ordinary differential equations, Fourier series and integrals, the Laplace transformation, Bessel functions and Legendre polynomials, and an introduction to partial differential equations.

Prerequisites
Differential and integral calculus. Students with no experience in linear algebra may find it helpful to take 625.250 Applied Mathematics I first.

Course Notes
Not for graduate credit.

Instructor: D'Arghangelo

625.260  Introduction to Linear Systems
This course is designed primarily for students who do not have a bachelor's degree in electrical engineering. The course may be useful to those with general interests in systems analysis, control systems, and/or signal processing. Topics include signal representations, linearity, time-variance, convolution, and Fourier series and transforms. Coverage includes both continuous and discrete-time systems. Practical applications in filter design, modulation/demodulation, and sampling are introduced.

Prerequisites
Differential and integral calculus.

Course Notes
Not for graduate credit.

Instructor: Woolf

625.401  Real Analysis
This course presents a rigorous treatment of fundamental concepts in analysis. Emphasis is placed on careful reasoning and proofs. Topics covered include the completeness and order properties of real numbers, limits and continuity, conditions for integrability and differentiability, infinite sequences, and series. Basic notions of topology and measure are also introduced.

Prerequisites
Multivariate calculus.

Instructor: Hill

625.402  Modern Algebra
This course examines the structures of modern algebra, including groups, linear spaces, rings, polynomials, and fields, and some of their applications to such areas as cryptography, primality testing and the factorization of composite numbers, efficient algorithm design in computing, circuit design, and signal processing. It will include an introduction to quantum information processing. Grading is based on weekly problem sets, a midterm, and a final.

Prerequisites
Multivariate calculus and linear algebra.

Instructor: Johnston

625.403  Statistical Methods and Data Analysis
This course introduces commonly used statistical methods. The intent of this course is to provide an understanding of statistical techniques and guidance on the appropriate use of methodologies. The course covers the mathematical foundations of common methods as an aid toward understanding both the types of applications that are appropriate and the limits of the methods. MATLAB and statistical software are used so students can apply statistical methodology to practical problems in the workplace. Topics include the basic laws of probability and descriptive statistics, conditional probability, random variables, expectation and variance, discrete and continuous probability models, bivariate distributions and covariance, sampling distributions, hypothesis testing, method of moments and maximum likelihood point (MLE) estimation, confidence intervals, contingency tables, analysis of variance (ANOVA), and linear regression modeling.

Prerequisites
Multivariate calculus.

Instructors: Bodt, Savkli, Wang
625.404  Ordinary Differential Equations
This course provides an introduction to the theory, solution, and application of ordinary differential equations. Topics discussed in the course include methods of solving first-order differential equations, existence and uniqueness theorems, second-order linear equations, power series solutions, higher-order linear equations, systems of equations, non-linear equations, Sturm-Liouville theory, and applications. The relationship between differential equations and linear algebra is emphasized in this course. An introduction to numerical solutions is also provided. Applications of differential equations in physics, engineering, biology, and economics are presented. This course covers more material at greater depth than the standard undergraduate-level ODE course.

Prerequisites
Two or more terms of calculus are required. Course in linear algebra would be helpful.

Instructor: Farris

625.409  Matrix Theory
In this course, topics include the methods of solving linear equations, Gaussian elimination, triangular factors and row exchanges, vector spaces (linear independence, basis, dimension, and linear transformations), orthogonality (inner products, projections, and Gram-Schmidt process), determinants, eigenvalues and eigenvectors (diagonal form of a matrix, similarity transformations, and matrix exponential), singular value decomposition, and the pseudo-inverse. The course also covers applications to statistics (least squares fitting to linear models, covariance matrices) and to vector calculus (gradient operations and Jacobian and Hessian matrices). MATLAB software will be used in some class exercises.

Instructors: Rio, Wall

625.411  Computational Methods
As the need to increase the understanding of real-world phenomena grows rapidly, computer-based simulations and modeling tools are increasingly being accepted as viable means to study such problems. In this course, students are introduced to some of the key computational techniques used in modeling and simulation of real-world phenomena. The course begins with coverage of fundamental concepts in computational methods including error analysis, matrices and linear systems, convergence, and stability. It proceeds to curve fitting, least squares, and iterative techniques for practical applications, including methods for solving ordinary differential equations and simple optimization problems. Elements of computer visualization and Monte Carlo simulation will be discussed as appropriate. The emphasis here is not so much on programming technique, but rather on understanding basic concepts and principles. Employment of higher-level programming and visualization tools, such as MATLAB, reduces burdens on programming and introduces a powerful tool set commonly used by industry and academia. A consistent theme throughout the course is the linkage between the techniques covered and their applications to real-world problems.

Prerequisites
Multivariate calculus and ability to program in MATLAB, FORTRAN, C++, Java, or other language. Courses in matrix theory or linear algebra as well as in differential equations would be helpful but are not required.

Instructor: Joyce

625.414  Linear Optimization
Optimization is the act of obtaining the best result while satisfying given constraints. This course focuses mainly on linear programming and the geometry of linear systems. Though “straightforward” in nature, linear programs have a wide variety of real-world applications such as production planning, worker scheduling, and resource allocation. Linear programming is used in a number of fields: manufacturing, transportation, and military operations are just a few. In this course, we will cover solution techniques for linear programs, including the simplex method, the revised simplex method, the dual simplex method, and, time permitting, interior point methods. We will also investigate linear programming geometry and duality, theorems of the alternative, and sensitivity analysis. In parallel with our theoretical development, we will consider how to formulate mathematical programs for a variety of applications including familiar network models such as the assignment, transshipment, transportation, shortest path, and maximum flow problems. We will also present some methods and applications for integer programming problems (e.g., branch and bound and cutting plane methods) and discuss the role of multiobjective linear programming and goal programming in this area.

Prerequisites
Multivariate calculus, linear algebra. Some real analysis would be good but is not required.

Instructor: Castello

625.415  Nonlinear Optimization
Although a number of mathematical programming problems can be formulated and solved using techniques from linear and integer problems, there are a wide variety of problems that require the inclusion of nonlinearities if they are to be properly modeled. This course presents theory and algorithms for solving nonlinear optimization problems. Theoretical topics treated include basic convex analysis, first- and second-order optimality conditions, KKT conditions, constraint qualification, and duality theory. We will investigate an array of algorithms for both constrained and unconstrained optimization. These algorithms include the Nelder-Mead (nonlinear simplex method), steepest descent, Newton methods, conjugate direction methods, penalty methods, and barrier methods. In parallel with our theoretical and algorithmic development, we will consider how to formulate mathematical programs for an assortment of applications including facility location, regression analysis, financial evaluation, and policy analysis. If
time permits, we will also address algorithms for special classes of nonlinear optimization problems (e.g., separable programs, convex programs, and quadratic programs).

Prerequisites
Multivariate calculus, linear algebra. Some real analysis would be good but is not required; 625.414 (Linear Optimization) is not required.

Instructor: Castello

625.417 Applied Combinatorics and Discrete Mathematics

Combinatorics and discrete mathematics are increasingly important fields of mathematics because of their extensive applications in computer science, statistics, operations research, and engineering. The purpose of this course is to teach students to model, analyze, and solve combinatorial and discrete mathematical problems. Topics include elements of graph theory, graph coloring and covering circuits, the pigeonhole principle, counting methods, generating functions, recurrence relations and their solution, and the inclusion-exclusion formula. Emphasis is on the application of the methods to problem solving. (This course is the same as 605.423 Applied Combinatorics and Discrete Mathematics.)

Instructor: Whisnant

625.420 Mathematical Methods for Signal Processing

This course familiarizes the student with modern techniques of digital signal processing and spectral estimation of discrete-time or discrete-space sequences derived by the sampling of continuous-time or continuous-space signals. The class covers the mathematical foundation needed to understand the various signal processing techniques as well as the techniques themselves. Topics include the discrete Fourier transform, the discrete Hilbert transform, the singular-value decomposition, the wavelet transform, classical spectral estimates (periodogram and correlogram), autoregressive and autoregressive-moving average spectral estimates, and Burg maximum entropy method.

Prerequisites
Mathematics through calculus, matrix theory, or linear algebra, and introductory probability theory and/or statistics. Students are encouraged to refer any questions to the instructor.

Instructor: Boules

625.423 Introduction to Operations Research: Probabilistic Models

This course investigates several probability models that are important to operations research applications. Models covered include Markov chains, Markov processes, renewal theory, queuing theory, scheduling theory, reliability theory, Bayesian networks, random graphs, and simulation. The course emphasizes both the theoretical development of these models and the application of the models to areas such as engineering, computer science, and management science.

Prerequisites
Multivariate calculus and a course in probability and statistics (such as 625.403). Some familiarity with optimization is desirable but not necessary.

Instructor: Perry

625.436 Graph Theory

This course focuses on the mathematical theory of graphs; a few applications and algorithms will be discussed. Topics include trees, connectivity, Eulerian and Hamiltonian graphs, matchings, edge and vertex colorings, independent sets and cliques, planar graphs, and directed graphs. An advanced topic completes the course. Familiarity with linear algebra and basic counting methods such as binomial coefficients is assumed. Comfort with reading and writing mathematical proofs is required.

Prerequisites
Linear algebra.

Instructor: DeVinney

625.438 Neural Networks

This course provides an introduction to concepts in neural networks and connectionist models. Topics include parallel distributed processing, learning algorithms, and applications. Specific networks discussed include Hopfield networks, bidirectional associative memories, perceptrons, feedforward networks with back propagation, and competitive learning networks, including self-organizing and Grossberg networks. Software for some networks is provided. (This course is the same as 605.447 Neural Networks.)

Prerequisites
Multivariate calculus and linear algebra.

Instructor: Fletcher

625.441 Mathematics of Finance

This course offers a rigorous treatment of the subject of investment as a scientific discipline. Mathematics is employed as the main tool to convey the principles of investment science and their use to make investment calculations for good decision making. Topics covered in the course include the basic theory of interest and its applications to fixed-income securities, cash flow analysis and capital budgeting, mean-variance portfolio theory and the associated capital asset pricing model, utility function theory and risk analysis, derivative securities and basic option theory, and portfolio evaluation.

Prerequisites
Multivariate calculus and an introductory course in probability and statistics (such as 625.403). Some familiarity with optimization is desirable but not necessary.

Instructor: Perry

625.442 Mathematics of Risk, Options, and Financial Derivatives

The concept of options stems from the inherent human desire and need to reduce risks. This course starts with a rigorous
mathematical treatment of options pricing, credit default swaps, and related areas by developing a powerful mathematical tool known as Ito calculus. We introduce and use the well-known field of stochastic differential equations to develop various techniques as needed, as well as discuss the theory of martingales. The mathematics will be applied to the arbitrage pricing of financial derivatives, which is the main topic of the course. We treat the Black-Scholes theory in detail and use it to understand how to price various options and other quantitative financial instruments. We also discuss interest rate theory. We further apply these techniques to investigate stochastic differential games, which can be used to model various financial and economic situations including the stock market. Time permitting, we discuss related topics in mechanism designs, a subfield of game theory that is concerned about designing economic games with desired outcome.

Prerequisites
Multivariate calculus, linear algebra and matrix theory (e.g., 625.409), and a graduate-level course in probability and statistics (such as 625.403).

Course Notes
This class is distinguished from 625.441 Mathematics of Finance (formerly 625.439) and 625.714 Stochastic Differential Equations, as follows: 625.441 gives a broader and more general treatment of financial mathematics, and 625.714 provides a deeper (more advanced) mathematical understanding of stochastic differential equations, with applications in both finance and non-finance areas. No one of the classes 625.441, 625.442, and 625.714 is a prerequisite or co-requisite for the other classes; the classes are intended to be complementary. Feel free to contact the instructor(s) should you have any questions about these courses.

Instructor: Chin

625.461 Linear Models and Regression
Introduction to regression and linear models including least squares estimation, maximum likelihood estimation, the Gauss-Markov Theorem, and the Fundamental Theorem of Least Squares. Topics include estimation, hypothesis testing, simultaneous inference, model diagnostics, transformations, multicollinearity, influence, model building, and variable selection. Advanced topics include nonlinear regression, robust regression, and generalized linear models including logistic and Poisson regression.

Prerequisites
One semester of statistics (such as 625.403), multivariate calculus, and linear algebra.

Instructor: Staff

625.462 Design and Analysis of Experiments
Statistically designed experiments are the efficient allocation of resources to maximize the amount of information obtained with a minimum expenditure of time and effort. Design of experiments is applicable to both physical experimentation and computer simulation models. This course covers the principles of experimental design, the analysis of variance method, the difference between fixed and random effects and between nested and crossed effects, and the concept of confounded effects. The designs covered include completely random, randomized block, Latin squares, split-plot, factorial, fractional factorial, nested treatments and variance component analysis, response surface, optimal, Latin hypercube, and Taguchi. Any experiment can correctly be analyzed by learning how to construct the applicable design structure diagram (Hasse diagrams).

Prerequisites
Multivariate calculus, linear algebra, and one semester of graduate probability and statistics (e.g., 625.403 Statistical Methods and Data Analysis). Some computer-based homework assignments will be given.

Instructor: Bodt

625.463 Multivariate Statistics and Stochastic Analysis
Multivariate analysis arises with observations of more than one variable when there is some probabilistic linkage between the variables. In practice, most data collected by researchers in virtually all disciplines are multivariate in nature. In some cases, it might make sense to isolate each variable and study it separately. In most cases, however, the variables are interrelated in such a way that analyzing the variables in isolation may result in failure to uncover critical patterns in the data. Multivariate data analysis consists of methods that can be used to study several variables at the same time so that the full structure of the data can be observed and key properties can be identified. This course covers estimation, hypothesis tests, and distributions for multivariate mean vectors and covariance matrices. We also cover popular multivariate data analysis methods including multivariate data visualization, maximum likelihood, principal components analysis, multiple comparisons tests, multidimensional scaling, cluster analysis, discriminant analysis and multivariate analysis of variance, multiple regression and canonical correlation, and analysis of repeated measures data. Coursework will include computer assignments.

Prerequisites
Linear algebra, multivariate calculus, and one semester of graduate probability and statistics (e.g., 625.403).

Instructor: Hung

625.464 Computational Statistics
Computational statistics is a branch of mathematical sciences concerned with efficient methods for obtaining numerical solutions to statistically formulated problems. This course will introduce students to a variety of computationally intensive statistical techniques and the role of computation as a tool of discovery. Topics include numerical optimization in statistical inference [expectation-maximization (EM) algorithm, Fisher scoring, etc.], random number generation, Monte Carlo methods, randomization methods, jackknife methods, boot-
strap methods, tools for identification of structure in data, estimation of functions (orthogonal polynomials, splines, etc.), and graphical methods. Additional topics may vary. Coursework will include computer assignments.

**Prerequisites**
Multivariate calculus, familiarity with basic matrix algebra, graduate course in probability and statistics (such as 625.403).

**Instructor:** Nickel

### 625.480 Cryptography

An important concern in the information age is the security, protection, and integrity of electronic information, including communications, electronic funds transfer, power system control, transportation systems, and military and law enforcement information. Modern cryptography, in applied mathematics, is concerned not only with the design and exploration of encryption schemes (classical cryptography) but also with the rigorous analysis of any system that is designed to withstand malicious attempts to tamper with, disturb, or destroy it. This course introduces and surveys the field of modern cryptography. After mathematical preliminaries from probability theory, algebra, computational complexity, and number theory, we will explore the following topics in the field: foundations of cryptography, public key cryptography, probabilistic proof systems, pseudorandom generators, elliptic curve cryptography, and fundamental limits to information operations.

**Prerequisites**
Linear algebra and an introductory course in probability and statistics such as 625.403 Statistical Methods and Data Analysis.

**Instructor:** Johnston

### 625.485 Number Theory

This course covers principal ideas of classical number theory, including the fundamental theorem of arithmetic and its consequences, congruences, cryptography and the RSA method, polynomial congruences, primitive roots, residues, multiplicative functions, and special topics.

**Prerequisites**
Multivariate calculus and linear algebra.

**Instructor:** Stern

### 625.487 Applied Topology

The course is both an introduction to topology and an investigation of various applications of topology in science and engineering. Topology, simply put, is a mathematical study of shapes, and it often turns out that just knowing a rough shape of an object (whether that object is as concrete as platonic solids or as abstract as the space of all paths in large complex networks) can enhance one’s understanding of the object. We will start with a few key theoretical concepts from point-set topology with proofs, while letting breadth take precedence over depth, and then introduce key concepts from algebraic topology, which attempts to use algebraic concepts, mostly group theory, to develop ideas of homotopy, homology, and cohomology, which render topology “computable.” Finally, we discuss a few key examples of real-world applications of computational topology, an emerging field devoted to the study of efficient algorithms for topological problems, especially those arising in science and engineering, which builds upon classical results from algebraic topology as well as algorithmic tools from computational geometry and other areas of computer science. The questions we like to ask are: Do I know the topology of my network? What is a rough shape of the large data set that I am working with (is there a logical gap?) Will the local picture of a part of the sensor field I am looking at give rise to a consistent global common picture? (This course is the same as 605.428 Applied Topology.)

**Prerequisites**
Multivariate calculus, linear algebra and matrix theory (e.g., 625.409), and an undergraduate-level course in probability and statistics.

**Instructor:** Chin

### 625.490 Computational Complexity and Approximation

This course will cover the theory of computational complexity, with a focus on popular approximation and optimization problems and algorithms. It begins with important complexity concepts including Turing machines, Karp and Turing reducibility, basic complexity classes, and the theory of NP-completeness. It then discusses the complexity of well-known approximation and optimization algorithms and introduces approximability properties, with special focus on approximation algorithm and heuristic design. The impact of emerging computing techniques, such as massive parallelism and quantum computing, will also be discussed. The course will specifically target algorithms with practical significance and techniques that can improve performance in real-world implementations.

**Prerequisites**
Introductory probability theory and/or statistics (such as 625.403) and undergraduate-level exposure to algorithms and matrix algebra. Some familiarity with optimization and computing architectures is desirable but not necessary.

**Instructor:** Wood

### 625.495 Time Series Analysis and Dynamic Modeling

This course will be a rigorous and extensive introduction to modern methods of time series analysis and dynamic modeling. Topics to be covered include elementary time series models, trend and seasonality, stationary processes, Hilbert space techniques, the spectral distribution function, autoregressive/integrated/moving average (ARIMA) processes, fitting ARIMA models, forecasting, spectral analysis, the periodogram, spectral estimation techniques, multivariate time series, linear systems and optimal control, state-space models, and Kalman filtering and prediction. Additional topics may be
covered if time permits. Some applications will be provided to illustrate the usefulness of the techniques.

**Prerequisites**
Graduate course in probability and statistics (such as 625.403) and familiarity with matrix theory and linear algebra.

**Course Notes**
This course is also offered in the Department of Applied Mathematics and Statistics (Homewood campus).

**Instructor:** Torcaso

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**625.703 Functions of a Complex Variable**
Topics include properties of complex numbers, analytic functions, Cauchy's theorem and integral formulas, Taylor and Laurent series, singularities, contour integration and residues, and conformal mapping.

**Prerequisites**
625.401 Real Analysis, or 625.404 Ordinary Differential Equations, or permission of the instructor.

**Instructors:** Weisman, Whisnant

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**625.710 Fourier Analysis with Applications to Signal Processing and Differential Equations**
This applied course covers the theory and application of Fourier analysis, including the Fourier transform, the Fourier series, and the discrete Fourier transform. Motivation will be provided by the theory of partial differential equations arising in physics and engineering. We will also cover Fourier analysis in the more general setting of orthogonal function theory. Applications in signal processing will be discussed, including the sampling theorem and aliasing, convolution theorems, and spectral analysis. Finally, we will discuss the Laplace transform, again with applications to differential equations.

**Prerequisites**
Familiarity with differential equations, linear algebra, and real analysis.

**Instructor:** Spencer

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**625.714 Introductory Stochastic Differential Equations with Applications**
The goal of this course is to give basic knowledge of stochastic differential equations useful for scientific and engineering modeling, guided by some problems in applications. The course treats basic theory of stochastic differential equations including weak and strong approximation, efficient numerical methods and error estimates, the relation between stochastic differential equations and partial differential equations, Monte Carlo simulations with applications in financial mathematics, population growth models, parameter estimation, and filtering and optimal control problems.

**Prerequisites**
Multivariate calculus and a graduate course in probability and statistics, and exposure to ordinary differential equations.

**Instructor:** Burkhardt

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**625.717 Advanced Differential Equations: Partial Differential Equations**
This course presents practical methods for solving partial differential equations (PDEs). The course covers solutions of hyperbolic, parabolic, and elliptic equations in two or more independent variables. Topics include Fourier series, separation of variables, existence and uniqueness theory for general higher-order equations, eigenfunction expansions, finite difference and finite element numerical methods, Green's functions, and transform methods. MATLAB, a high-level computing language, is used throughout the course to complement the analytical approach and to introduce numerical methods.

**Prerequisites**
625.404 Ordinary Differential Equations or equivalent graduate-level ODE class and knowledge of eigenvalues and eigenvectors from matrix theory. (Note: The standard undergraduate-level ODE class alone is not sufficient to meet the prerequisites for this class.)

**Instructors:** Farris, Whisnant

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**625.718 Advanced Differential Equations: Nonlinear Differential Equations and Dynamical Systems**
This course examines ordinary differential equations from a geometric point of view and involves significant use of phase plane diagrams and associated concepts, including equilibrium points, orbits, limit cycles, and domains of attraction. Various methods are discussed to determine existence and stability of equilibrium points and closed orbits. Methods are discussed for analyzing nonlinear differential equations (e.g., linearization, direct, perturbation, and bifurcation analysis). An introduction to chaos theory and Hamiltonian systems is also presented. The techniques learned will be applied to equations from physics, engineering, biology, ecology, and neural networks (as time permits).

**Prerequisites**
625.404 Ordinary Differential Equations or equivalent graduate-level ODE class and knowledge of eigenvalues and eigenvectors from matrix theory. (Note: The standard undergraduate-level ODE class alone is not sufficient to meet the prerequisites for this class.) 625.717 is not required.

**Instructors:** Farris, Whisnant

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**625.721 Probability and Stochastic Process I**
The course is an introduction to probability theory. Topics include sample space, combinatorial analysis, conditional probability, discrete and continuous distributions, expectation and generating functions, laws of large numbers, and central limit theorem. This course is proof oriented, and the primary purpose is to lay the foundation for the second course, 625.722, and other specialized courses in probability.

**Prerequisites**
Multivariate calculus and 625.403 Statistical Methods and Data Analysis or equivalent.

**Instructor:** Aminzadeh
625.722  Probability and Stochastic Process II
This course is an introduction to the theory of discrete-time stochastic processes. Emphasis in the course is given to Poisson processes, renewal theory, renewal reward process, Markov chains, continuous-time Markov chains, birth and death process, Brownian motion, and random walks.

Prerequisites
Differential equations and 625.721 Probability and Stochastic Process I or equivalent.
Instructor: Aminzadeh

625.725  Theory of Statistics I
This course covers mathematical statistics and probability. Topics covered include discrete and continuous probability distributions, expected values, moment-generating functions, sampling theory, convergence concepts, and the central limit theorem. This course is a rigorous treatment of statistics that lays the foundation for 625.726 and other advanced courses in statistics.

Prerequisites
Multivariate calculus and 625.403 Statistical Methods and Data Analysis or equivalent.
Instructor: Aminzadeh

625.726  Theory of Statistics II
This course is the continuation of 625.725. It covers method of moments estimation, maximum likelihood estimation, the Cramer-Rao inequality, sufficiency and completeness of statistics, uniformly minimum variance unbiased estimators, the Neyman-Pearson Lemma, the likelihood ratio test, goodness-of-fit tests, confidence intervals, selected non-parametric methods, and decision theory.

Prerequisites
625.725 Theory of Statistics I or equivalent.
Instructor: Aminzadeh

625.728  Measure-Theoretic Probability
This course provides a rigorous, measure-theoretic introduction to probability theory. It begins with the notion of fields, sigma-fields, and measurable spaces, and also surveys elements from integration theory and introduces random variables as measurable functions. It then examines the axioms of probability theory and fundamental concepts including conditioning, conditional probability and expectation, independence, and modes of convergence. Other topics covered include characteristic functions, basic limit theorems (including the weak and strong laws of large numbers), and the central limit theorem.

Prerequisites
625.401 Real Analysis and 625.403 Statistical Methods and Data Analysis.
Instructor: Hill

625.734  Queuing Theory with Applications to Computer Science
Queues are a ubiquitous part of everyday life; common examples are supermarket checkout stations, help desk call centers, manufacturing assembly lines, wireless communication networks, and multi-tasking computers. Queuing theory provides a rich and useful set of mathematical models for the analysis and design of service process for which there is contention for shared resources. This course explores both theory and application of fundamental and advanced models in this field. Fundamental models include single and multiple server Markov queues, bulk arrival and bulk service processes, and priority queues. Applications emphasize communication networks and computer operations but may include examples from transportation, manufacturing, and the service industry. Advanced topics may vary. (This course is the same as 605.725 Queuing Theory with Applications.)

Prerequisites
Multivariate calculus and a graduate course in probability and statistics such as 625.403.
Instructor: Nickel

625.740  Data Mining
Data mining is a relatively new term used in the academic and business world, often associated with the development and quantitative analysis of very large databases. Its definition covers a wide spectrum of analytic and information technology topics, such as machine learning, pattern recognition, artificial intelligence, statistical modeling, and efficient database development. This course will review these broad topics and cover specific analytic and modeling techniques such as data cleaning techniques, principal components, regression, decision trees, neural networks, support vector machines, nearest neighbor, clustering, association rules, generalization error, and the holdout, cross-validation, and bootstrap methods. Mathematics underlying these techniques will be discussed, and their application to real-world data will be illustrated. Because use of the computer is extremely important when mining large amounts of data, we will make substantial use of data mining software tools to learn the techniques and analyze datasets.

Prerequisites
Multivariate calculus, linear algebra, and matrix theory (e.g., 625.409), and a course in probability and statistics (such as 625.403). This course will also assume familiarity with multiple linear regression and basic ability to program.
Instructor: Weisman

625.741  Game Theory
Game theory is a field of applied mathematics that describes and analyzes interactive decision making when two or more parties are involved. Since finding a firm mathematical footing in 1928, it has been applied to many fields, including economics, political science, foreign policy, and engineering. This course will serve both as an introduction to and a survey
of applications of game theory. Therefore, after covering the mathematical foundational work with some measure of mathematical rigor, we will examine many real-world situations, both historical and current. Topics include two-person/N-person game, cooperative/non-cooperative game, static/dynamic game, combinatorial/strategic/coalitional game, and their respective examples and applications. Further attention will be given to the meaning and the computational complexity of finding of Nash equilibrium. (This course is the same as 605.726 Game Theory.)

**Prerequisites**
Multivariate calculus, linear algebra and matrix theory (e.g., 625.409), and a course in probability and statistics (such as 625.403).

**Instructor:** Chin

### 625.743 Stochastic Optimization and Control
Stochastic optimization plays an increasing role in the analysis and control of modern systems. This course introduces the fundamental issues in stochastic search and optimization, with special emphasis on cases where classical deterministic search techniques (steepest descent, Newton-Raphson, linear and nonlinear programming, etc.) do not readily apply. These cases include many important practical problems, which will be briefly discussed throughout the course (e.g., neural network training, nonlinear control, experimental design, simulation-based optimization, sensor configuration, image processing, discrete-event systems, etc.). Both global and local optimization problems will be considered. Techniques such as random search, least mean squares (LMS), stochastic approximation, simulated annealing, evolutionary computation (including genetic algorithms), and machine learning will be discussed.

**Prerequisites**
Multivariate calculus, familiarity with basic matrix algebra, graduate course in probability and statistics (such as 625.403). Some computer-based homework assignments will be given. It is recommended that this course be taken only in the last half of a student's degree program.

**Instructor:** Spall

### 625.744 Modeling, Simulation, and Monte Carlo
Computer simulation and related Monte Carlo methods are widely used in engineering, scientific, and other work. Simulation provides a powerful tool for the analysis of real-world systems when the system is not amenable to traditional analytical approaches. In fact, recent advances in hardware, software, and user interfaces have made simulation a “first-line” method of attack for a growing number of problems. Areas where simulation-based approaches have emerged as indispensable include decision aiding, prototype development, performance prediction, scheduling, and computer-based personnel training. This course introduces concepts and statistical techniques that are critical to constructing and analyzing effective simulations and discusses certain applications for simulation and Monte Carlo methods. Topics include random number generation, simulation-based optimization, model building, bias-variance tradeoff, input selection using experimental design, Markov chain Monte Carlo (MCMC), and numerical integration.

**Prerequisites**
Multivariate calculus, familiarity with basic matrix algebra, graduate course in probability and statistics (such as 625.403). Some computer-based homework assignments will be given. It is recommended that this course be taken only in the last half of a student's degree program.

**Instructor:** Spall

### 625.800 Independent Study in Applied and Computational Mathematics
An individually tailored, supervised project on a subject related to applied and computational mathematics. A maximum of one independent study course may be applied toward the master of science degree or post-master's certificate. This course may only be taken in the second half of a student's degree program. All independent studies must be supervised by an ACM instructor and must rely on material from prior ACM courses. The independent study project proposal form must be approved prior to registration.

**Instructor:** Staff
Applied Biomedical Engineering

Biomedical engineering is the application of knowledge from engineering and physics to enhance the understanding of and provide solutions to problems in biology and medicine. The goal of the master of science in Applied Biomedical Engineering program is to educate and train practicing scientists and engineers to be able to carry out engineering-oriented research and development in the biomedical sciences.

The strength of the Applied Biomedical Engineering program lies in the active involvement of the faculty in research and development. The majority of the courses are offered at the Applied Physics Laboratory campus; however, some electives are offered only at the Homewood campus.

Program Committee

Eileen Haase, Program Chair
Instructor, Biomedical Engineering
Whiting School of Engineering

Isaac N. Bankman, Program Vice chair
Principal Professional Staff, Applied Physics Laboratory
Assistant Professor of Biomedical Engineering,
School of Medicine

Murray B. Sachs
Principal Professional Staff, Applied Physics Laboratory
Professor of Biomedical Engineering, School of Medicine

Admission Requirements

Applicants must meet the general requirements for admission to a graduate program outlined in this catalog in Admission Requirements (page 4). In addition, the applicant must have compiled an average of B (3.0 on a 4.0 scale) or above for all courses in mathematics, physics, engineering, and the other physical and biological sciences. The applicant’s preparation must have included: (1) mathematics, through ordinary differential equations; (2) calculus-based physics, including mechanics, heat and energy, electricity and magnetism, and elementary quantum concepts; and (3) chemistry. Noncredit courses in organic chemistry and mathematics are offered for those who may need them to satisfy the eligibility requirements or to refresh their knowledge. The noncredit mathematics course is offered in the Applied and Computational Mathematics program.

Course Requirements

I. Noncredit Courses

585.209 Organic Chemistry
625.201 General Applied Mathematics

II. Required Courses

Five one-semester courses depending on the focus area:

Instrumentation Focus Area

585.405/406 Physiology for Applied Biomedical Engineering
585.408 Medical Sensors and Devices
585.409 Mathematical Methods for Applied Biomedical Engineering

Lab: Students must complete the equivalent of one course as lab/project work: 580.471/771 (highly recommended) or 585.800, 585.423 and 585.424, or 580.495 (with permission).

Imaging Focus Area

585.405/406 Physiology for Applied Biomedical Engineering
585.408 Medical Sensors and Devices
585.409 Mathematical Methods for Applied Biomedical Engineering

Lab: Students must complete the equivalent of one course as lab/project work: 580.800 (highly recommended), 585.423 and 585.424.
Biomaterials Focus Area
585.405/406 Physiology for Applied Biomedical Engineering
585.407 Molecular Biology
585.608 Biomaterials
Lab: Students must complete the equivalent of one course as lab/project work: 585.800, 585.423 and 585.424, or 580.420 (with permission) or 580.451/452 (1/2 credit) (with permission).

Systems Biology Focus Area
This focus area includes Computational Biology.
585.405/406 Physiology for Applied Biomedical Engineering
585.407 Molecular Biology
585.409 Mathematical Methods for Applied Biomedical Engineering
Lab: Students must complete the equivalent of one course as lab/project work: 585.423 and 585.424 (highly recommended) or 585.800. Alternatively, one of the following may be taken with permission: 580.420, 580.471/771, 580.495, or 580.683.

III. Elective Courses
The following elective courses are offered at the Applied Physics Laboratory or the Dorsey Center.
585.605 Medical Imaging
585.606 Medical Image Processing
585.607 Medical Imaging II: MRI
585.608 Biomaterials
585.609 Cell Mechanics
585.610 Biochemical Sensors
585.611 Practices of Biomedical Engineering
585.614 Applications of Physics and Technology to Biomedicine
585.618 Biological Fluid and Solid Mechanics
585.620 Orthopedic Biomechanics
585.624 Neural Prosthetics: Science, Technology, and Applications
585.634 Biophotonics
585.800 Special Project in Applied Biomedical Engineering
585.801 Directed Studies in Applied Biomedical Engineering

The following elective courses are offered during the day at the Homewood campus or the medical school. (These may be taken for credit if the prerequisites can be satisfied and with the approval of the instructor.)

IV. Elective Courses (Homewood)
580.420 Build-a-Genome
585.423/424 Laboratory in Systems Bioengineering, I and II
580.439/639 Models of Physiological Processes in the Neuron
580.442 Tissue Engineering
580.448 Biomechanics of Cells and Organisms
580.451/452 Cellular and Tissue Engineering Laboratory
580.466 Statistical Methods in Imaging
580.471 Principles of the Design of Biomedical Instrumentation II: Physiological and Clinical
580.473 Modern Biomedical Imaging, Instrumentation, and Techniques
580.476 Magnetic Resonance in Medicine
580.477 Advanced Topics in Magnetic Resonance Imaging
580.488/688 Foundations of Computational Biology and Bioinformatics II
580.491/691 Learning Theory
580.495 Microfabrication Laboratory
580.616 Introduction to Linear Systems
580.625/626 Structure and Function of the Auditory and Vestibular Systems
580.628 Topics in Systems Neuroscience
580.630 Theoretical Neuroscience
580.632 Ionic Channels in Excitable Membranes
580.641 Cellular Engineering
580.651 Introduction to Nonlinear Dynamics in Physiology
580.677 Advanced Topics in Magnetic Resonance Imaging
580.682 Computational Models of the Cardiac Myocyte
580.688 Foundations of Computational Biology and Bioinformatics II
580.690 Systems Biology of Cell Regulation
580.702/703 Neuroengineering Seminar
580.771 Principles of Biomedical Instrumentation

Course Descriptions
585.209 Organic Chemistry
This course offers an in-depth review and study of organic chemistry. Topics include the fundamental chemistry of carbon compounds, chemical bonding, synthesis, reaction mechanisms, and stereochemistry. The role of organic chemistry in biology and medicine, environmental science, and industry is discussed. (Not for credit for the Master of Science in Applied Biomedical Engineering degree.)

Instructor: Potember
585.405/406  **Physiology for Applied Biomedical Engineering**

This two-semester sequence is designed to provide the physiological background necessary for advanced work in biomedical engineering. A quantitative model-oriented approach to physiological systems is stressed. First-term topics include the cell and its chemistry, transport and the cell membrane, properties of excitable tissue and muscle, the cardiovascular system, and the respiratory system. The second-term course covers anatomy of the nervous system, structure and functions of the auditory and visual systems, motor systems, the kidney and gastrointestinal tract, and the neural and neuroendocrine control of the circulation.

**Instructors:** Berman, Haase, Staff

585.407  **Molecular Biology**

The course is intended to serve as a fundamental introduction to cell and molecular biology. Topics generally included are basic chemistry and biochemistry of the cell; structure, function, and dynamics of macromolecules; cell organization; enzyme kinetics; membranes and membrane transport; biochemistry of cellular energy cycles, including oxidative phosphorylation; replication, transcription, and translation; regulation of gene expression; and recombinant DNA technology. Where appropriate, biomedical application and devices based on principles from cell and molecular biology are emphasized.

**Prerequisites**
Prerequisite: 585.209 Organic Chemistry.

**Instructors:** DiNovo-Collela, Potember

585.408  **Medical Sensors and Devices**

This course covers the basic and advanced principles, concepts, and operations of medical sensors and devices. The origin and nature of measurable physiological signals are studied, including chemical, electrochemical, optical, and electromagnetic signals. The principles and devices to make the measurements, including a variety of electrodes and sensors, will be discussed first. This will be followed by a rigorous presentation of the design of appropriate electronic instrumentation. Therapeutic instrumentation such as pacemakers, defibrillators, and prosthetic devices will be reviewed. The final part of this course will cover emerging frontiers of cellular and molecular instrumentation and the use of micro- and nanotechnology in these biotechnology fields. The lectures will be followed by realistic experimentation in two laboratory sessions where students will obtain hands-on experience with electronic components, sensors, biopotential measurements, and testing of therapeutic instrumentation.

**Instructors:** Thakor, Staff

585.409  **Mathematical Methods for Applied Biomedical Engineering**

The course covers mathematical techniques needed to solve advanced problems encountered in applied biomedical engineering. Fundamental concepts are presented with emphasis placed on applications of these techniques to biomedical engineering problems. Topics include solution of ordinary differential equations using the Laplace transformation, Fourier series, and integrals; solution of partial differential equations including the use of Bessel functions and Legendre polynomials; and an introduction to complex analysis.

**Prerequisites**
Familiarity with multi-variable calculus, linear algebra, and ordinary differential equations.

**Instructor:** Rio

585.423/424  **Laboratory in Systems Bioengineering, I and II**

A two-semester laboratory course in which various physiological preparations are used as examples of problems of applying technology in biological systems. The emphasis in this course is on the design of experimental measurements and on physical models of biological systems.

585.605  **Medical Imaging**

This course examines fundamental physical concepts, instrumentation, and signal processing techniques used to produce images in radiography, ultrasonography, tomography, magnetic resonance imaging, and nuclear medicine.

**Prerequisites**
585.409 Mathematical Methods for Applied Biomedical Engineering or equivalent.

**Instructors:** Fainchtein, Staff

585.606  **Medical Image Processing**

This course covers digital image processing techniques used for the analysis of medical images such as x-ray, ultrasound, CT, MRI, PET, microscopy, etc. The presented image enhancement algorithms are used for improving the visibility of significant structures as well as for facilitating subsequent automated processing. The localization and identification of target structures in medical images are addressed with several segmentation and pattern recognition algorithms of moderate complexity. Image reconstruction algorithms used for three-dimensional image formation are presented. The course covers image registration algorithms used to determine the correspondence of multiple images of the same anatomical structure. Image compression algorithms applied to medical images are also addressed.

**Prerequisites & Notes**
Prerequisite: Familiarity with linear algebra and Fourier transforms.

**Instructors:** Bankman, Pham, Spisz

585.607  **Medical Imaging II: MRI**

Following the increasing use and development of new MRI methods, a course on advanced MRI concepts and applications was designed as part of the imaging area of emphasis.
Medical Imaging II provides more information on the physics, imaging procedures, and advanced techniques of MRI, and also includes two lectures on nuclear medicine.

**Prerequisites**
585.409 Mathematical Methods for Applied Biomedical Engineering or equivalent.

**Instructor:** Spector

**585.608 Biomaterials**
This course covers the fundamentals of the synthesis, properties, and biocompatibility of metallic, ceramic, polymeric, and biological materials that come in contact with tissue and biological fluids. Emphasis is placed on using biomaterials for both hard- and soft-tissue replacement, organ replacement, coatings and adhesives, dental implants, and drug delivery systems. New trends in biomaterials, such as electrically conductive polymers, piezoelectric biomaterials, and sol-gel processing, are discussed, and the recent merging of cell biology and biochemistry with materials is examined. Case studies and in-class scenarios are frequently used to highlight the current opportunities and challenges of using biomaterials in medicine.

**Prerequisites**
585.209 Organic Chemistry

**Instructor:** Potember

**585.609 Cell Mechanics**
The class starts with introductory lectures on the place of cell mechanics in the broader areas of cell biology, physiology, and biophysics, where the general topics of cell structure, motility, force generation, and interaction with the extracellular matrix are considered. Three important case studies are discussed: blood cells, vascular endothelial cells, and cochlear hair cells. The analysis of each of these cases includes constitutive relations, experiments to estimate cellular parameters, and biological and physiological implications. The constitutive relations are based on nonlinear viscoelasticity in the cases of blood and endothelial cells and linear piezoelectricity in the case of hair cells. The necessary components of engineering mechanics of solids and fluids are introduced. The effective mechanical characteristics of the cell are related to the structure and properties of the cellular membrane, cytoskeleton, and nucleus. Micropipette aspiration, atomic force microscopy, and magnetic cytometry techniques are discussed in detail. Students also read and make presentations of original journal papers covering additional topics, exposing them to the professional literature and honing their communication skills.

**Instructor:** Spector

**585.610 Biochemical Sensors**
This course covers the fundamental principles and practical aspects of chemical sensing of physiological signals. The focus of the course is on the electrochemistry and biophysical chemistry of biological sensing elements and their integration with signal transducers. Other topics covered include design and construction of practical sensors, processing and interpretation of signal outputs, and emerging technologies for biosensing.

**Instructors:** Bryden, Potember

**585.611 Practices of Biomedical Engineering**
The goal of this course is to present a methodical approach to practical biomedical engineering. The topics include innovation in research and engineering; contracting with the federal government; writing business plans and technical proposals; legal issues such as liability, patents, and the FDA approval process; the practice of biomedical engineering in industry; approaches to biomedical problems, including systems engineering and prototyping; and other issues involved in managing a research program, such as marketing, sales, service, and other economic factors. A team of leading biomedical engineers and technical program managers teaches the course.

**Instructors:** Potember, Staff

**585.614 Applications of Physics and Technology to Biomedicine**
The goal of this course is to expose students to several concrete examples of how physical and technological methods are used in biomedicine. Examples will be chosen from ophthalmology (e.g., how the optical properties of the eye’s cornea are related to its ultrastructure, applications of lasers, methods of measuring ocular blood flow and intraocular pressure), biomedical optics (e.g., microscopy, optical coherence tomography), neural signal processing, medical image processing, and MRI. Topics will be presented by instructors who are actively engaged in research in the various areas.

**Instructors:** McCally, Staff

**585.618 Biological Fluid and Solid Mechanics**
The goal of this class is to learn the relation between the mechanics and physiology (biology) of tissues and cells. This relation is demonstrated by introducing general models of solid and fluid mechanics and applying them to the cardiovascular system and bones. In particular, the arterial wall and endothelial cell mechanics as well as bone anisotropic properties and remodeling are discussed. The course also shows how theoretical models are used to interpret experiments and how experimental data are used to estimate important parameters (constants) of the models. Experiments with biaxial stretching, micropipette aspiration, and atomic force microscopy commonly used to probe the mechanical properties of tissues and cells are discussed in detail. The models include anisotropic linear elasticity, nonlinear elasticity, viscoelasticity, and Newtonian (non-Newtonian) fluid dynamics.

**Instructor:** Spector

**585.620 Orthopedic Biomechanics**
This course serves as an introduction to the field of orthopedic biomechanics for the biomedical engineer. Structure and function of the musculoskeletal system in the intact and pathologic states will be reviewed. Further discussion will
focus on the design of orthopedic implants for the spine and the appendicular skeleton. Biomechanical principles of fracture repair and joint reconstruction will also be addressed. Peer-reviewed journal publications will be used to explore the latest developments in this field.

**Prerequisites**
585.405/406 Physiology for Applied Biomedical Engineering (or equivalent).

**Instructor:** Dimitriev

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**585.624 Neural Prosthetics: Science, Technology, and Applications**

This course addresses the scientific bases, technologies, and chronic viability of emerging neuroprosthetic devices. Examples include cochlear and retinal implants for sensory restoration, cortical and peripheral nervous system and brain computer interface devices for deriving motor control and enabling afferent feedback, rehabilitative and therapeutic devices such as deep-brain stimulators for Parkinson’s disease, functional electrical stimulation systems for spinal cord injuries, and cognitive prosthetic systems for addressing brain trauma. Regulatory (FDA) challenges with emerging technologies and ethical considerations will also be addressed.

**Instructors:** Harshbarger, Staff

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**585.634 Biophotonics**

This course introduces the fundamental principles of biophotonics and their applications to real-world devices. In a combination of laboratory and classroom exercises, students will design optical systems for evaluation of optical properties of biological media and learn computational methods to simulate light transport in such media. Modern optical measurement techniques including fluorescence spectroscopy, optical coherence tomography, and confocal microscopy will be covered in detail.

**Instructors:** Ramella-Roman, Sova

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**585.800 Special Project in Applied Biomedical Engineering**

This course is an individually tailored, supervised project that offers the student research experience through work on a special problem related to the student's specialty or interest. The research problem can be addressed experimentally or analytically. A written report is produced on which the grade is based. The applied biomedical engineering project proposal form must be completed prior to registration.

**Prerequisites**
Permission of the instructor.

**Instructor:** Staff

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**585.801 Directed Studies in Applied Biomedical Engineering**

The course permits the student to investigate possible research fields or pursue topics of interest through reading or non-laboratory study under the direction of a faculty member. The applied biomedical engineering directed studies program proposal form must be completed prior to registration.

**Prerequisites**
Permission of the instructor.

**Instructor:** Staff

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**580.439/639 Models of Physiological Processes in the Neuron**

This course treats single neuron modeling, including molecular models of channels and channel gating, Hodgkin-Huxley-style models of membrane currents, nonlinear dynamics as a way of understanding membrane excitability, neural integration through cable theory, and network computation. The goal of the course is to understand how neurons work as biological computing elements and also to give students experience with modeling techniques as applied to complex biological systems.

**Prerequisites**
Mathematics through linear algebra and differential equations and an introduction to neuroscience (e.g., 580.422, 080.205, or 080.304); introductory signal and system theory (e.g. 580.222 or 520.213/214) is helpful.

**Course Notes**
There may be extra requirements for graduate students taking 580.639.

**Instructor:** Young

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**580.442 Tissue Engineering**

This course focuses on the application of engineering fundamentals to designing biological tissue substitutes. Concepts of tissue development, structure, and function will be introduced. Students will learn to recognize the majority of histological tissue structures in the body and understand the basic building blocks of the tissue and clinical need for replacement. The engineering components required to develop tissue-engineered grafts will be explored including biomechanics and transport phenomena along with the use of biomaterials and bioreactors to regulate the cellular microenvironment. Emphasis will be placed on different sources of stem cells and their applications to tissue engineering. Clinical and regulatory perspectives will be discussed. Co-listed with 580.642.

**Prerequisites**
580.221 or 020.305 and 020.306, 030.205. **Recommended** 580.441/580.641.

**Instructors:** Elisseff, Grayson
580.476 Magnetic Resonance in Medicine
This course provides the student with a complete introduction to the physical principles, hardware design, and signal processing used in magnetic resonance imaging and magnetic resonance spectroscopy. The course is designed for students who wish to pursue research in magnetic resonance.

Prerequisites
580.222 Systems and Controls or 520.214 Signals and Systems. Co-listed with 580.673 and 520.673 (the 673 course is usually the graduate level course).

Instructor: Bottomley, Edelstein, Herzka
When Offered: Fall

580.625/626 Structure and Function of the Auditory and Vestibular Systems
This course covers the physiological mechanisms of hearing and balance. Topics include transmission of sound in the ear, transduction of sound and head orientation by hair cells, biophysics and biochemistry of hair cells, representation of sound and balance in eighth-nerve discharge patterns, anatomy of the central auditory and vestibular systems, and synaptic transmission and signal processing in central neurons. Aspects of hearing and balance such as speech perception, sound localization, vestibular reflexes, and vestibular compensation are discussed with an integrated perspective covering perceptual, physiological, and mechanistic data.

Prerequisites
585.405/406 Physiology for Applied Biomedical Engineering or equivalent. Recommended: 110.302 Differential Equations, 520.214 Signals and Systems.

Instructor: Hearing Science Center Staff
When Offered: Fall (even years), spring (odd years)

580.628 Topics in Systems Neuroscience
This course consists of weekly discussions of current literature in systems neuroscience. The selected readings will focus on neural mechanisms for perception, attention, motor behavior, learning, and memory, as studied using physiological, psychophysical, computational, and imaging techniques. Students are expected to give presentations and participate in discussions.

Prerequisites
Intro. to Neuroscience, 110.302, 520.214, 580.421 or equivalent.

Instructors: Wang, Zhang
When Offered: Fall

580.630 Theoretical Neuroscience
This course covers theoretical methods for analyzing information encoding and representing function in neural systems, including models of single and multiple neural spike trains based on stochastic processes and information theory, detection and estimation of behaviorally relevant parameters from spike trains, system theoretic methods for analyzing sensory receptive fields, and network models of neural systems. Both theoretical methods and the properties of specific well-studied neural systems will be discussed.

Prerequisites
Introduction to Neuroscience (585.406 or equivalent), 550.420 Probability or equivalent, and 520.214 Signals and Systems.

Instructors: Wang, Young

580.632 Ionic Channels in Excitable Membranes
Ionic channels are key signaling molecules that support electrical communication throughout the body. As such, these channels are a central focus of biomedical engineering as it relates to neuroscience, computational biology, biophysics, and drug discovery. This course introduces the engineering (stochastic and mathematical models) and molecular strategies (cloning and expression) used to understand the function of ionic channels. The course also surveys key papers that paint the current picture of how channels open (gating) and conduct ions (permeation). Biological implications of these properties are emphasized throughout. Finally, the course introduces how optical (fluorescence methods) and electrophysiological methods (patch clamp) now promise to revolutionize understanding of ionic channels. This course can be viewed as a valuable partner of Models of Physiological Processes in the Neuron (580.439). Advanced homework problems, paper presentations, and exam questions are added to the core curriculum.

Prerequisites
585.405/406 Physiology for Applied Biomedical Engineering or equivalent. Recommended: 585.409 Mathematical Methods for Applied Biomedical Engineering, signals, and elementary probability.

Instructor: Yue
When Offered: Fall (even years)

585.633 Biosignals
This course focuses on how signal analysis can clarify the understanding of biomedical signal interpretation and diagnosis. Topics include EEGs, ECGs, and EMGs (how they are generated and measured), biosignals as random processes, spectral analysis, wavelets, time-frequency functions, and signal processing for pattern recognition.

Prerequisites
585.409 Mathematical Methods for Applied Biomedical Engineering or equivalent; students will be expected to learn MATLAB; introductory-level probability and statistics.

Instructor: Sherman

580.634 Molecular and Cellular Systems Physiology Laboratory
This course provides laboratory experience in cell imaging, motility, and excitation; stochastic simulation of ionic channel gating; and expression and biophysical characterization of
cloned and native ionic channels. Students work on one or two projects from this set, under faculty supervision.

**Prerequisites**
585.405/406 Physiology for Applied Biomedical Engineering or equivalent.

**Instructors:** Tung, Yue

**When Offered:** Spring (odd years)

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**580.638 Cell Mechanics and Motility**
Fundamental to their function, cells generate and respond to mechanical forces. For example, whole muscle cells contract, but all cells must move chromosomes during cell division. This class will cover macroscopic mechanics of cells and their cytoskeleton, physical models of force generation, and molecular models derived from recent atomic structures of force-generating proteins. Clinical effects, such as cardiomyopathies where these processes are defective, and new molecular measurement technologies will also be discussed. An interdisciplinary approach spanning molecular biology, biochemistry, physics, and engineering will be emphasized.

**Prerequisites**
585.407 Molecular Biology or equivalent, 585.405/406 Physiology for Applied Biomedical Engineering or equivalent.

**Instructor:** Kuo

**When Offered:** Spring (odd years)

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**580.641 Cellular Engineering**
This course focuses on principles and applications in cell engineering. Class lectures include an overview of molecular biology fundamentals, protein/ligand binding, receptor/ligand trafficking, cell-cell interactions, cell-matrix interactions, and cell adhesion and migration at both theoretical and experimental levels. Lectures will cover the effects of physical (e.g., shear stress, strain), chemical (e.g., cytokines, growth factors), and electrical stimuli on cell function, emphasizing topics on gene regulation and signal transduction processes. Furthermore, topics in metabolic engineering, enzyme evolution, polymeric biomaterials, and drug and gene delivery will be discussed. This course is intended as Part 1 of a two-semester sequence recommended for students in the Cell and Tissue Engineering focus area. Meets with 580.441.

**Prerequisites**
580.221 or 020.305 and 020.306 (or equivalent) and 030.205

**Instructors:** Green, Yarema

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**580.644 Neural Control of Movement and Vocalization**
Generating a sound with our vocal system or moving our arm are both examples of a goal-directed movement. This is a course that compares the neural mechanisms responsible for acquisition of sensory information and generation of motion in these two motor behaviors. We will explore the brain systems that integrate (1) visual and somatosensory information in order to produce limb movements, and (2) auditory information in order to vocalize a sound. Emphasis is on experimental and theoretical results on the primate brain.

**Prerequisites**
585.406 Physiology for Applied Biomedical Engineering or equivalent course in neuroscience.

**Instructors:** Shadmehr, Wang

**When Offered:** Fall

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**580.651 Introduction to Nonlinear Dynamics in Physiology**
This course is designed for students who may be interested in applying the techniques of nonlinear dynamics and chaos to the analysis of physiological data. Topics covered will include fractals, strange attractors, bifurcations, state-space attractor reconstruction, Poincaré sections, dimension calculations, Lyapunov exponents, entropy, tests for determinism, and nonlinear forecasting. Examples will be drawn from studies in cardiology, brain function, and the oculomotor system.

**Prerequisites & Notes**
585.405/406 Physiology for Applied Biomedical Engineering or equivalent, 585.409 Mathematical Methods for Applied Biomedical Engineering, basic knowledge of signals and systems or permission of instructor.

**Course Notes**
Limited enrollment.

**Instructor:** Shelhamer

**When Offered:** Fall (even years)

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**580.682 Computational Models of the Cardiac Myocyte**
The cardiac myocyte is one of the most extensively studied cells in biology. As such, it serves as an important example of how to develop quantitative, dynamic, computational models of cell function. This course will present a comprehensive review of all aspects of modeling of the cardiac myocyte as an introduction to the discipline of computational cell biology. Students will read and present key papers from the literature, implement and study computer models of the cardiac myocyte, and complete a project. Requirements are knowledge of a programming language (MATLAB, C, C++, Java are satisfactory), a course in ordinary differential equations, and an introductory course in molecular and/or systems biology.

**Prerequisites**
585.405/406 Physiology for Applied Biomedical Engineering or equivalent, 585.409 Mathematical Methods for Applied Biomedical Engineering.

**Instructors:** Greenstein, Winslow

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**580.683 High Performance Computing in Biology**
This course trains students in the use of high performance computing systems to solve problems in biological modeling. Lecture topics include: (1) review of high performance computing in molecular modeling, biological fluid dynamics and transport, and cell network modeling; (2) efficient
numerical methods for use on high performance computing systems; and (3) architecture and programming of the symmetric vector processor and the symmetric multiprocessing Silicon Graphics Power Challenge XL systems. Material is presented both in lectures and supervised laboratory sessions, during which students do interactive programming.

**Prerequisites**
Introductory programming, UNIX, 585.409 Mathematical Methods for Applied Biomedical Engineering (differential equations and linear algebra).

**Instructors:** Jafri, Winslow

**When Offered:** Spring

### 580.684 Experimental Foundations for Neural Models

This course familiarizes students with the experimental tools that are used to provide the biological data base for neural models. Projects are designed to teach single-unit recording in sensory nerve, characterization of complex receptive fields, cellular or synaptic potential measurement, evoked potential techniques, and psychophysical measurement of sensory or motor function.

**Prerequisites**
585.406 Physiology for Applied Biomedical Engineering or equivalent introductory course on the nervous system and permission of instructor.

**Instructors:** Sachs, Staff

**When Offered:** Spring

### 580.688 Foundations of Computation Biology and Bioinformatics II

This course will introduce probabilistic modeling and information theory applied to biological sequence analysis, focusing on statistical models of protein families, alignment algorithms, and models of evolution. Topics will include probability theory, score matrices, hidden Markov models, maximum likelihood, expectation maximization, and dynamic programming algorithms. Homework assignments will require programming in Python. Foundations of Computational Biology I is not a prerequisite.

**Prerequisites**

**Instructor:** Karchin

### 580.690 Systems Biology of Cell Regulation

This course will explore the recent advances in systems biology analysis of intracellular processes. Examples of the modeling and experimental studies of metabolic, genetic, signal transduction and cell cycle regulation networks will be studied in detail. The classes will alternate between consideration of network-driven and network element (gene, metabolite, or protein)-driven approaches.
Applied Physics

The applied physicist bridges the gap between pure physics and engineering by conducting research on technical applications of natural phenomena. The hallmark of the applied physicist is the ability to conceive solutions by applying fundamental physical principles to complex problems.

The graduate program in applied physics leads to the master of science degree and is designed to develop professionals with broad capabilities appropriate for careers in technical research or advanced graduate study. Because of today's changing technology, the program encompasses a wide range of topics, enabling the graduate to contribute solutions to a variety of physics problems. The faculty of the Applied Physics program is drawn predominantly from the staff of the Applied Physics Laboratory. Faculty interests and expertise include the following areas of specialization: ocean sciences, optics, solid-state physics, materials, and space sciences. In their areas of research, the faculty members collaborate with colleagues from various divisions of the university, as well as with scientists and engineers at other national and international laboratories.

**Program Committee**

*Harry K. Charles Jr., Program Chair*
Principal Professional Staff
Applied Physics Laboratory

*Robert C. Cammarata*
Professor, Materials Science and Engineering
Whiting School of Engineering

*Richard F. Gasparovic*
Principal Professional Staff
Applied Physics Laboratory

*David L. Porter*
Principal Professional Staff
Applied Physics Laboratory

*John C. Sommerer*
Principal Professional Staff
Applied Physics Laboratory

*Joseph J. Suter*
Principal Professional Staff
Applied Physics Laboratory

*Michael E. Thomas*
Principal Professional Staff
Applied Physics Laboratory

**Admission Requirements**

Applicants must meet the general requirements for admission to a graduate program outlined in Admission Requirements (page 4). The applicant's education also must have included mathematics through vector analysis and ordinary differential equations, general physics, modern physics, intermediate mechanics, and intermediate electricity and magnetism. The intermediate mechanics and intermediate electricity and magnetism requirements may be waived if the applicant has an exceptionally good grade-point average and a strong background in mathematics.

**Course Requirements and Course Descriptions**

A total of 10 one-term courses must be completed within five years. The core curriculum requires four courses, with at least three courses selected from a group of six designed to provide a mastery of physical principles (mathematical physics, electromagnetics, quantum mechanics, classical mechanics, statistical mechanics and thermodynamics, and modern physics). The fourth core course can be selected from either the basic physical principal offerings above or from a group of three courses (Principles of Optics, Materials Science, and Physical System Modeling) that provide an introduction to the three primary curriculum concentration areas (geophysical and space sciences, photonics, and materials and condensed matter). Four of the remaining six courses must be selected from among the Applied Physics courses listed below and may follow a particular concentration or contain a variety of Applied Physics courses. The two remaining courses may be selected from any of the offerings of the Whiting School of Engineering with the approval of the student's advisor.

Four of the 10 courses required for the degree must be at the 700 or 800 level. With the advisor's approval, an elective course may be substituted for a required course if the student has previously completed an equivalent graduate-level course. Academic standards governing graduate study must be maintained.

Neither a thesis nor knowledge of a foreign language is required in this program.

Courses numbered 600 level and above are open only to those students who have been admitted for graduate study. Some courses may not be offered every year. Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

**I. Required Courses**

Four one-term courses, with at least three selected from the first six courses below:

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<th>Course Code</th>
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<td>Mathematical Methods for Physics and Engineering</td>
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II. Elective Courses
Six one-term courses, with at least four from Applied Physics:

A. Applied Physics Electives

Geophysics and Space Science
- 615.444 Space Systems I
- 615.445 Space Systems II
- 615.462 Introduction to Astrophysics
- 615.748 Introduction to Relativity
- 615.753 Plasma Physics
- 615.755 Space Physics
- 615.761 Introduction to Oceanography
- 615.769 Physics of Remote Sensing
- 615.772 Cosmology
- 615.775 Physics of Climate

Photonics
- 615.751 Modern Optics
- 615.758 Modern Topics in Applied Optics
- 615.778 Computer Optical Design
- 615.780 Optical Detectors and Applications
- 615.781 Quantum Information Processing
- 615.782 Optics and MATLAB

Materials and Condensed Matter
- 615.446 Physics of Magnetism
- 615.447 Fundamentals of Sensors
- 615.481 Polymeric Materials
- 615.746 Nanoelectronics: Physics and Devices
- 615.747 Sensors and Sensor Systems
- 615.757 Solid-State Physics
- 615.760 Physics of Semiconductor Devices

Energy
- 615.421 Electric Power Principles
- 615.448 Alternate Energy Technology
- 615.731 Photovoltaic and Solar Thermal Energy Conversion

Additional
- 615.762 Applied Computational Electromagnetics
- 615.765 Chaos and Its Applications
- 615.779 Computational Physics
- 615.800 Applied Physics Project
- 615.802 Directed Studies in Applied Physics

B. General Electives
The remaining elective one-term courses may be selected from those listed above and/or from other master of science programs described in this catalog, subject to approval by the student’s advisor.

Photonics Concentration
Students can elect to concentrate their studies in photonics by completing a combination of courses from the Applied Physics and Electrical and Computer Engineering curricula. Applied physics students specializing in photonics must complete the three required courses listed below plus one additional course from the required Electrical and Computer Engineering Photonics core.

Admission Requirements
Applicants must meet the general requirements for admission to graduate programs outlined in Admission Requirements (page 4). In addition, applicants must meet the specific program requirements for either Applied Physics or Electrical and Computer Engineering. The special concentration in photonics will be noted on the student’s transcript.

Course Requirements
A total of 10 one-term courses must be completed.

Photonics Concentration—Applied Physics Required Courses
- 615.441 Mathematical Methods for Physics and Engineering
- 615.454 Quantum Mechanics
- 615.471 Principles of Optics

Photonics Concentration—Electrical and Computer Engineering Core Courses
Select one:
- 525.413 Fourier Techniques in Optics
- 525.425 Laser Fundamentals
- 525.491 Fundamentals of Photonics

Photonics Concentration—Electives in Applied Physics
Applied Physics offers several additional optics courses. Of the remaining six courses, four or more must be photonics courses selected from both the Applied Physics and Electrical and Computer Engineering curricula.

- 615.751 Modern Optics
- 615.758 Modern Topics in Applied Optics
- 615.778 Computer Optical Design
- 615.780 Optical Detectors and Applications
- 615.781 Quantum Information Processing
- 615.782 Optics and MATLAB

Note: 615.800 Applied Physics Project and 615.802 Directed Studies in Applied Physics can also be used to allow the student to pursue specialized interests in optics.

Photonics Concentration—Electives in Electrical and Computer Engineering
Electrical and Computer Engineering offers the following photonics courses:
- 525.413 Fourier Techniques in Optics
- 525.425 Laser Fundamentals
- 525.436 Optics and Photonics Laboratory
- 525.491 Fundamentals of Photonics
Applied Physics

525.753 Laser Systems and Applications  
525.756 Optical Propagation, Sensing, and Backgrounds  
525.772 Fiber-Optic Communication Systems  
525.792 Electro-Optical Systems  
525.796 Introduction to High-Speed Electronics and Optoelectronics  
525.797 Advanced Optics and Photonics Laboratory

Note: 525.801 and 525.802 Special Project courses can also be used to allow students to pursue specialized interests in optics.

Materials and Condensed Matter Concentration

Students can elect to concentrate their studies in materials and condensed matter by completing a combination of courses from the Applied Physics, Electrical and Computer Engineering, and Materials Science and Engineering curricula. Applied Physics students specializing in materials and condensed matter must complete three of the first six required courses listed above, plus 615.480 Materials Science.

Of the remaining six courses, four or more must be materials and condensed matter courses selected from the Applied Physics, Electrical and Computer Engineering, Materials Science and Engineering, and Chemical and Biomolecular Engineering curricula.

Applied Physics

Offers the following materials-related courses:

615.446 Physics of Magnetism  
615.447 Fundamentals of Sensors

Course Descriptions

Courses numbered 600 level and above are open only to those students who have been admitted for graduate study. Some courses may not be offered every year. Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

615.421 Electric Power Principles

This is an introductory course on electric power, its distribution, and its applications. The first half of the course focuses on the physics of electric power and its generation, with an emphasis on distribution and distribution systems. Topics to be covered include AC voltages and currents, transmission lines, mono- and poly-phase systems, and losses due to electromagnetic forces. The second half of the course is directed toward applications. Specific applications covered include system analysis and protection, power electronics, induction and permanent magnet motors, transformers, etc. At least one lecture will be used to bring all the concepts together by studying the implementation of an alternative power generation system using wind turbines. During the course of the term, several research papers on power generation and distribution will be read and summarized by the students. A term paper on an electric power subject may be required.

Instructor: Clancy

615.441 Mathematical Methods for Physics and Engineering

This course covers a broad spectrum of mathematical techniques essential to the solution of advanced problems in physics and engineering. Topics include ordinary and partial differential equations, contour integration, tabulated integrals, saddle-point methods, linear vector spaces, boundary-value problems, eigenvalue problems, Green’s functions, integral transforms, and special functions. Application of these topics to the solution of problems in physics and engineering is stressed.

Prerequisites

Vector analysis and ordinary differential equations (linear algebra and complex variables recommended).

Instructor: Adelmann
615.442 Electromagnetics
Maxwell’s equations are derived and applied to the study of topics including electrostatics, magnetostatics, propagation of electromagnetic waves in vacuum and matter, antennas, wave guides and cavities, microwave networks, electromagnetic waves in plasmas, and electric and magnetic properties of materials.

Prerequisites
Knowledge of vector analysis, partial differential equations, Fourier analysis, and intermediate electromagnetics.

Instructor: Awadallah

615.444 Space Systems I
This course is intended for the physicist or engineer interested in the design of space experiments and space systems. The course presents the fundamental technical background, current state of the art, and example applications. Topics include systems engineering, space environment, astrodynamics, propulsion and launch vehicles, attitude determination and control, and space power systems. (This course may be taken for 700-level credit with additional requirement of a research paper.)

Prerequisites
An undergraduate degree in physics or engineering or the equivalent.

Instructor: Staff

615.445 Space Systems II
This course examines the fundamentals necessary to design and develop space experiments and space systems. The course presents the technical background, current state of the art, and example applications. Topics include spacecraft thermal control, spacecraft configuration and structural design, space communications, command and telemetry systems, data processing and storage, reliability and quality assurance, and systems integration and testing. (This course may be taken for 700-level credit with the additional requirement of a research paper.)

Prerequisites
An undergraduate degree in physics or engineering or the equivalent. Although preferable, it is not necessary to have taken 615.444 or 615.744 Space Systems I.

Instructor: Lesho

615.446 Physics of Magnetism
This is an introductory course on the magnetic properties of materials and magnetic systems. The emphasis of the course is a mastery of the physics of magnetism along with detailed examples and applications. A basic review of magnetic fields and various classical applications is given. Topics include the physics of paramagnetism, diamagnetism, and ferromagnetism. The magnetism of metals is presented along with discussion of Landau levels and the quantum Hall effect. Various applications are presented in detail, including magnetic resonance, spectroscopic techniques, magnetoresistance, and spintronics.

Prerequisites
An undergraduate degree in engineering, physics, or a related technical discipline. Prior knowledge of electromagnetic interactions would be helpful but not required.

Instructor: Clancy

615.447 Fundamentals of Sensors
Students will receive an overview of sensors and methods to build networks and systems using sensors. The physics of detectors including fundamental technologies and sampling interfaces will be discussed. Sensor technologies for chemical, biological, nuclear, and radiological detection will be studied in detail. Evaluation methods will be presented for sensor selection based on application specific information including sensor performance, environmental conditions, and operational impact. DODAF 2.0 methods will be taught, and a project based on several viewpoints will be required and presented. Additional studies will include methods for combining results from various sensors to increase detection confidence. As part of the course, students will be given a threat scenario and will be required to select a sensor suite and networking information to design a hypothetical system considering the threat, sensor deployment cost, and logistics.

Prerequisites
An undergraduate degree in engineering, physics, or a related technical discipline.

Instructor: Lesho

615.448 Alternate Energy Technology
Energy availability and its cost are major concerns to every person. Fossil fuels in general and oil in particular are limited and the world’s reserves are depleting. The question asked by many is, “Are there alternatives to the fossil fuel spiral (dwindling supplies and rising costs)?” This course addresses these alternative energy sources. It focuses on the technology basis of these alternate energy methods, as well as the practicality and the potential for widespread use and economic effectiveness. Energy technologies to be considered include photovoltaics, solar thermal, wind energy, geothermal and thermal gradient sources, biomass and synthetic fuels, hydroelectric, wave and tidal energy, and nuclear. The associated methods of energy storage will also be discussed.

Prerequisites
An undergraduate degree in engineering, physics, or a related technical discipline.

Instructor: Charles

615.451 Statistical Mechanics and Thermodynamics
After a brief historical review of thermodynamics and statistical mechanics, the basic principles of statistical mechanics are presented. The classical and quantum mechanical partition functions are discussed and are subsequently used to carry out derivations of the basic thermodynamic properties of several different systems. Topics discussed include Planck’s black
body radiation derivation and the Einstein-Debye theories of the specific heats of solids. The importance of these topics in the development and confirmation of quantum mechanics is also examined. Other topics discussed include Fermi-Dirac and the Bose-Einstein statistics and the cosmic background radiation. The importance of comparisons between theory and data is stressed throughout.

**Instructor:** Kundu

**615.453 Classical Mechanics**
This is an advanced course in classical mechanics that introduces techniques that are applicable to contemporary pure and applied research. The material covered provides a basis for a fundamental understanding of not only quantum and statistical mechanics but also nonlinear mechanical systems. Topics include the Lagrangian and Hamiltonian formulation of classical mechanics, Euler’s rigid body equations of motion, Hamilton-Jacobi theory, and canonical perturbation theory. These methods are applied to force-free motion of a rigid body, oscillations of systems of coupled particles, and central force motion including the Kepler problem and scattering in a Coulomb potential. Applications are emphasized through in-class examples and homework.

**Prerequisites**
Intermediate mechanics and 615.441 Mathematical Methods for Physics and Engineering.

**Instructor:** Freund

**615.454 Quantum Mechanics**
This is a course in advanced modern physics that presents the basic concepts and mathematical formalism of quantum mechanics and introduces applications in atomic, molecular, and solid-state physics. Topics include the mathematics of quantum mechanics, one-dimensional problems, central field problems, the interaction of electromagnetic radiation with atomic systems, the harmonic oscillator, angular momentum, and perturbation theory.

**Prerequisites**
615.441 Mathematical Methods for Physics and Engineering or the equivalent.

**Instructor:** Najmi

**615.462 Introduction to Astrophysics**
The techniques and fundamental theories of modern astrophysics are covered with special emphasis on the sun and stars. Topics include stellar structure, opacity of gases, radiative and convective transfer of energy, spectroscopic technique, and interpretation of stellar spectra. Stellar and solar magnetism and the role of magnetic fields in stellar atmospheres are also discussed.

**Prerequisites**
615.442 Electromagnetics or the equivalent and 615.454 Quantum Mechanics.

**Instructor:** Najmi

**615.465 Modern Physics**
This course covers a broad spectrum of topics related to the development of quantum and relativity theories. The understanding of modern physics and its applications is essential to the pursuit of advanced work in materials, optics, and other applied sciences. Topics include the special theory of relativity, particle-like properties of light, wavelike properties of particles, wave mechanics, atomic and nuclear phenomena, elementary particles, statistical physics, solid state, astrophysics, and general relativity.

**Prerequisites**
Undergraduate degree in physics or engineering.

**Instructor:** Hawkins

**615.471 Principles of Optics**
This course teaches the student the fundamental principles of geometrical optics, optical instruments, radiometry, vision, and the measurement of color. It begins with a review of basic Gaussian optics to prepare the student for the more advanced concepts. From Gaussian optics, the course leads the students through the principles of ray-trace analysis to develop a detailed understanding of the properties of an optical system. The causes and techniques for the correction of aberrations are studied. The course covers the design principles of optical instruments, telescopes, microscopes, etc. The techniques of light measurement are covered in sessions on radiometry and photometry. The elevation of optical sensors and their performance limits are covered. The limitations imposed by the human eye are discussed, and the description and measurement of color are reviewed.

**Prerequisites**
Undergraduate degree in physics or engineering.

**Instructors:** Edwards, Ohl

**615.480 Materials Science**
This course covers a broad spectrum of materials-related topics designed to prepare the student for advanced study in the materials arena. Topics include atomic structure, atom and ionic behavior, defects, crystal mechanics, strength of materials, material properties, fracture mechanics and fatigue, phase diagrams and phase transformations, alloys, ceramics, polymers, and composites.

**Prerequisites**
Undergraduate degree in physics or engineering.

**Instructor:** Charles

**615.481 Polymeric Materials**
This is a comprehensive course in polymeric materials. Topics include natural (biological) polymers, polymer synthesis, polymer morphology, inorganic polymers, ionomers, and polymeric materials applications. Composite materials containing polymers will also be discussed. A portion of the course will be devoted to the evaluation of polymer properties by physical methods.

**Instructor:** Staff
615.731 Photovoltaic and Solar Thermal Energy Conversion
This is an advanced course in the application of science and technology to the field of solar energy in general and photovoltaic and solar thermal energy systems in particular. The foundations of solar energy are described in detail to provide the student with the knowledge to evaluate and/or design complete solar thermal or photovoltaic energy systems. Topics range from the theoretical principles of solar radiation to the advanced design of both photovoltaic and solar thermal energy collectors. A major feature of the course is the understanding and design of semiconducting photovoltaic devices (solar cells). Solar cell topics include semiconductors, analysis of p-n junction, Shockley-Queisser limit, non-radiative recombination processes, antireflection coating, crystalline silicon solar cells, thin-film solar cells, and rechargeable batteries. Solar thermal energy topics include solar heat collectors, solar water heaters, solar power systems, sensible heat energy storage, phase transition thermal storage, etc. The course will also present optimizing building designs for a solar energy system.
Instructor: Sova

615.744 Space Systems I
This course is intended for the physicist or engineer interested in the design of space experiments and space systems. The course presents the fundamental technical background, current state of the art, and example applications. Topics include systems engineering, space environment, astrodynamics, propulsion and launch vehicles, attitude determination and control, and space power systems. This course requires the completion of a research paper. (This course may be taken for 400-level credit without the requirement of a research paper.)
Prerequisites
An undergraduate degree in physics or engineering or the equivalent.
Instructor: Staff

615.745 Space Systems II
This course examines the fundamentals necessary to design and develop space experiments and space systems. The course presents the theoretical background, current state of the art, and examples of the disciplines essential to developing space instrumentation and systems. Experts in the field will cover the following topics: spacecraft attitude determination and control, space communications, satellite command and telemetry systems, satellite data processing and storage, and space systems integration and testing. This course requires the completion of a research paper. (This course is also offered for 400-level credit and does not require completion of a research paper.)
Prerequisites
An undergraduate degree in physics or engineering or the equivalent. Although preferable, it is not necessary to have taken 615.444 or 615.744 Space Systems I.
Instructor: Staff

615.746 Nanoelectronics: Physics and Devices
This course provides an introduction to state-of-the-art and potential future electronics technologies. The first part of the course focuses on the physics of advanced silicon technology and on its scaling limits. The treatment includes a discussion of future electronics as projected to the year 2012 by the Semiconductor Industry Association’s National Technology Roadmap for Semiconductors. This understanding of conventional technology then motivates the second part of the course, which covers some of the “new” physics currently being explored for going beyond the roadmap. Topics range from the reasonably practical to the highly speculative and include tunneling transistors, single-flux quantum logic, single-electronics, spin-based electronics, quantum computing, and perhaps even DNA-based computing. An overview is also given of the prospects for advances in fabrication technology that will largely determine the economic viability for any of these possible electronic futures.
Prerequisites
615.760 Physics of Semiconductor Devices or equivalent.
Instructor: Charles

615.747 Sensors and Sensor Systems
The primary objective of this course is to present recent advances made in the field of sensors. A broad overview includes radiation, biological, magnetic, fiber optic, and acoustic sensors. The course will examine basic sensor operation and the implementation of sensors in measurement systems. Other topics to be covered are physical principles of sensing, interface electronic circuits, and sensor characteristics. The focus will be on practical application and state-of-the-art developments.
Instructor: Fitch

615.748 Introduction to Relativity
After a brief review of the theory of special relativity, the mathematical tools of tensor calculus that are necessary for understanding the theory of general relativity will be developed. Relativistic perfect fluids and their stress-energy-momentum tensor will be defined, and the Einstein’s field equations will be studied. Gravitational collapse will be introduced, and the Schwarzschild Black Hole solution will be discussed.
Instructor: Najmi

615.751 Modern Optics
This course covers the fundamental principles of modern optical and contemporary optical systems. Topics include propagation of light, polarization, coherence, interference, diffraction, Fourier optics, absorption, scattering, dispersion, and image quality analysis. Special emphasis is placed on the instrumentation and experimental techniques used in optical studies.
Prerequisites
615.442 Electromagnetics or the equivalent completed or taken concurrently.
Instructor: Boone
615.753 Plasma Physics
This course serves as an introduction to plasma phenomena relevant to energy generation by controlled thermonuclear fusion and space physics. Topics include motion of charged particles in electric and magnetic fields, dynamics of fully ionized plasma from both microscopic and macroscopic points of view, magnetohydrodynamics, equilibria, waves, instabilities, applications to fusion devices, ionospheric, and space physics.

Prerequisites
615.442 Electromagnetics or the equivalent.
Instructor: Ukhorskiy

615.755 Space Physics
This course studies the solar-terrestrial space environment and its importance for utilization of space. Topics include the solar cycle and magnetic dynamo; the electrodynamics of the solar upper atmosphere responsible for the solar wind; and the solar wind interaction with unmagnetized and magnetized bodies that leads to the treatment of ionospheres, planetary bow shocks, comets, and magnetospheres. Practical issues include penetrating radiation and its effects on spacecraft and man in space, catastrophic discharge phenomena, dust and hypervelocity impacts, material degradation by sputtering and reactive ionospheric constituents, atmospheric heating and orbital drag effects on satellites, and magnetospheric storm disruptions of ground power distribution.

Prerequisites
615.442 Electromagnetics or the equivalent.
Instructor: Dyrud

615.757 Solid-State Physics
Students examine concepts and methods employed in condensed matter physics, with applications in materials science, surface physics, and electronic devices. Topics include atomic and electronic structure of crystalline solids and their role in determining the elastic, transport, and magnetic properties of metals, semiconductors, and insulators. The effects of structural and chemical disorder on these properties are also discussed.

Prerequisites
615.454 Quantum Mechanics or the equivalent.
Instructor: Clancy

615.758 Modern Topics in Applied Optics
This course deals with optical system design involving state-of-the-art concepts. In particular, we will analyze the impact of nonlinearity in the propagation of laser beams and also the stochastic nature of light propagation in some commonly encountered situations such as atmospheric and undersea light propagation. Nonlinear interactions of light and matter play a significant role in a large portion of modern optical systems. In most situations, the optical system designer needs to eliminate or reduce nonlinearities and operate in a so-called linear regime. In other situations, the optical system takes advantage of the nonlinear interaction to produce significantly new operating conditions that are a significant key to the performance of modern optical systems. Similarly, taking into account the stochastic nature of light emission, detection, and propagation is important in the design and analyses of modern optical systems. The course reviews random processes involved in optical systems and applies statistical tools to identify the impact of such processes to the optical system performance.

Prerequisites
615.442 Electromagnetics and 615.782 Optics and MATLAB. A knowledge of laser fundamentals would also be helpful.
Instructor: Torruellas

615.760 Physics of Semiconductor Devices
This course examines the physical principles underlying semiconductor device operation and the application of these principles to specific devices. Emphasis is placed on understanding device operation, rather than on circuit properties. Topics include elementary excitations in semiconductors such as phonons, photons, conduction electrons, and holes; charge and heat transport; carrier trapping and recombination; effects of high doping; contacts; the pn junction; the junction transistor; surface effects; the MIS diode; and the MOSFET.

Prerequisites
Mathematics including differential equations and linear operators. Familiarity with quantum mechanics would be helpful.
Instructor: Charles

615.761 Introduction to Oceanography
This course covers the physical concepts and mathematics of the exciting field of oceanography and can be taken as an elective. It is designed for the student who wants to learn more about oceanography. Topics range from fundamental small waves to planetary-scale ocean currents. There will be a strong emphasis on understanding the basic ocean processes. Initial development gives a description of how the ocean system works and the basic governing equations. Additional subjects include boundary layers, flow around objects (seamounts), waves, tides, Ekman flow, and the Gulf Stream. Also studied will be the ocean processes that impact our climate such as El Nino and the Thermohaline Conveyor Belt.

Prerequisites
Mathematics through calculus.
Instructor: Porter

615.762 Applied Computational Electromagnetics
This course introduces the numerical methods and computer tools required for the practical applications of the electromagnetic concepts covered in 615.442 to the daily-life engineering problems. It covers the methods of calculating electromagnetic scattering from complex air and sea targets (aircraft, missiles, ships, etc.), taking into account the effects of the intervening atmosphere and natural surfaces such as the sea surface and terrain. These methods have direct applications in the areas of
rare imaging, communications, and remote sensing. Methods for modeling and calculating long-distance propagation over terrain and in urban areas, which find application in the areas of radar imaging, radio and TV broadcasting, and cellural communications, are also discussed. The numerical toolkit built in this course includes the method of moments, the finite difference frequency and time domain methods, the finite element method, marching numerical methods, iterative methods, and the shooting and bouncing ray method.

Prerequisites
Knowledge of vector analysis, partial differential equations, Fourier analysis, basic electromagnetics, and a scientific computer language.

Instructor: Awadallah

615.765 Chaos and Its Applications
The course will introduce the students to the basic concepts of nonlinear physics, dynamical system theory, and chaos. These concepts will be studied by examining the behavior of fundamental model systems that are modeled by ordinary differential equations and, sometimes, discrete maps. Examples will be drawn from physics, chemistry, and engineering. Some mathematical theory is necessary to develop the material. Practice through concrete examples will help to develop the geometric intuition necessary for work on nonlinear systems. Students conduct numerical experiments using provided software, which allows for interactive learning. Access to Whiting School computers is provided for those without appropriate personal computers.

Prerequisites
Mathematics through ordinary differential equations. Familiarity with MATLAB is helpful. Consult instructor for more information.

Instructor: Liakos

615.769 Physics of Remote Sensing
This course exposes the student to the physical principles underlying satellite observations of Earth by optical, infrared, and microwave sensors, as well as techniques for extracting geophysical information from remote sensor observations. Topics will include spacecraft orbit considerations, fundamental concepts of radiometry, electromagnetic wave interactions with land and ocean surfaces and Earth’s atmosphere, radiative transfer and atmospheric effects, and overviews of some important satellite sensors and observations. Examples from selected sensors will be used to illustrate the information extraction process and applications of the data for environmental monitoring, oceanography, meteorology, and climate studies.

Instructor: Gasparovic

615.772 Cosmology
This course begins with a brief review of tensor calculus and General Relativity principles, cosmological models, and theoretical and observational parameters that determine the fate of the universe. Basics of quantum fields necessary for an understanding of the Standard model and the early universe will be presented. Hubble expansion, the Cosmic Microwave Background Radiation (CMBR), recent theories of the presence of anisotropy in the CMBR, and their implications will be studied. The horizon problem and the role of the inflationary scenario in the early universe will be thoroughly explored.

Prerequisites
615.748 Introduction to Relativity.

Instructor: Najmi

615.775 Physics of Climate
To understand the forces that cause global climate variability, we must understand the natural forces that drive our weather and our oceans. This course covers the fundamental science underlying the nature of the Earth’s atmosphere and its ocean. This includes development of the basic equations for the atmosphere and ocean, the global radiation balance, description of oceanic and atmospheric processes, and their interactions and variability. Also included will be a description of observational systems used for climate studies and monitoring, and fundamentals underlying global circulation, and climate prediction models.

Prerequisites
Undergraduate degree in physics or engineering or equivalent, with strong background in mathematics through the calculus level.

Instructors: Porter, Winstead

615.778 Computer Optical Design
In this course, students learn to design and analyze optical systems. Students will use a full-function optical ray-trace program (either CODE V, OSLO, or ZEMAX), to be installed on their personal computers or those in the computer lab, to complete their assignments and design project. We will begin with simple lenses for familiarization with the software and then move onto more complicated multi-element lenses and reflective systems. Emphasis is placed on understanding the optical concepts involved in the designs while developing the ability to use the software. Upon completion of the course, students are capable of independently pursuing their own optical designs.

Prerequisites
615.471 Principles of Optics.

Instructor: Howard

615.780 Optical Detectors and Applications
This course examines the physics of detection of incoherent electromagnetic radiation from the infrared to the soft x-ray regions. Brief descriptions of the fundamental mechanisms of device operation are given. Typical source characteristics are mentioned to clarify detection requirements. Descriptions of non-spatially resolving detectors based on photoemission and photo-excitation follow, including background physics, noise, and sensitivity. Practical devices and practical operational con-
constraints are described. Description of scanning formats leads into the description of spatially revolving systems (e.g., staring arrays). Main emphasis is on charge-coupled devices and photo-emissive multiplier tubes such as the image intensifier. Selection of optimum detectors and integration into complete system designs are discussed. Applications in space-based and terrestrial remote sensing are discussed.

**Prerequisites**
615.471 Principles of Optics desired; undergraduate-level studies in solid-state physics and mathematics—preferably statistics—necessary.

**Instructor:** Koerner

**615.781 Quantum Information Processing**
This course provides an introduction to the rapidly developing field of quantum information processing. In addition to covering fundamental concepts such as two-state systems, measurements uncertainty, quantum entanglement, and non-locality, the course will emphasize specific quantum information protocols. Several applications of this technology will be explored, including cryptography, teleportation, dense coding, computing, and error correction. The quantum mechanics of polarized light will be used to provide a physical context to the discussion and will be supplemented with computer exercises. Current research on implementations of these ideas will also be discussed.

**Prerequisites**
615.454 Quantum Mechanics; familiarity with Mathematica helpful.

**Instructor:** Staff

**615.782 Optics and MATLAB**
This course provides hands-on experience with MATLAB by performing weekly computer labs revolving around optics. Each lab will explore a new topic in the optics field, while simultaneously providing experience in MATLAB. The goal is to bridge the gap between theoretical concepts and real-world applications or models. Topics include an introduction to MATLAB, Fourier theory and E&M propagation, image segmentation and pattern recognition, statistical optics, geometrical optics, interference and wave optics, holography and computer-generated holography, polarization, speckle phenomenon, and laser theory. Students are expected to complete weekly exercises in MATLAB and a semester project that will allow the student to investigate a particular topic of interest not specifically covered in the course.

**Prerequisites**
No prior experience with MATLAB is required. While a background in optics is helpful, it is not required.

**Instructor:** Torruellas

**615.800 Applied Physics Project**
This course is an individually tailored, supervised project that offers the student research experience through work on a special problem related to his or her field of interest. The research problem can be addressed experimentally or analytically, and a written report is produced.

**Prerequisites**
It is recommended that all required Applied Physics courses be completed. The Applied Physics project proposal form (available from the student’s advisor) must be approved prior to registration.

**Course Notes**
Open only to candidates in the Master of Science in Applied Physics program.

**Instructor:** Charles

**615.802 Directed Studies in Applied Physics**
In this course, qualified students are permitted to investigate possible research fields or to pursue problems of interest through reading or non-laboratory study under the direction of faculty members.

**Prerequisites**
The directed studies program proposal form (available from the student’s advisor) must be completed and approved prior to registration.

**Course Notes**
Open only to candidates in the Master of Science in Applied Physics program.

**Instructor:** Charles
Bioinformatics

Joint offering of the Zanvyl Krieger School of Arts and Sciences and the Whiting School of Engineering

Bioinformatics is proving to be a necessary tool for biologists, medical researchers, and drug designers in understanding genes, gene expression, SNPs, proteins, and pathways, as well as in studying disease. It is also playing an increasingly important role in identifying, characterizing, and selecting potential lead compounds and in understanding target molecules for drug development and production. As the biotechnology industry expands, a growing number of discoveries will move out of research laboratories and into commercial production. The explosion of sequence data from the human genome project and other large-scale and small-scale sequencing projects calls for skilled professionals who can develop and use sophisticated computer applications to unlock the information within the genetic code, with the ultimate goal of delivering life-saving therapies.

To meet the demand for skilled bioinformatics professionals, EP and the Zanvyl Krieger School of Arts and Sciences’ Advanced Academic Programs have joined forces to offer a degree in the new and rapidly evolving discipline that combines computer science and molecular biology. The bioinformatics degree draws on the faculty and resources from within each school to provide professionals with in-depth knowledge and technical skills in computational biology, preparing students for careers in bioinformatics and computational biology.

Graduates with the MS in Bioinformatics will have the educational foundation necessary to interpret complex biological information, perform analysis of sequence data using sophisticated bioinformatics software, and program software when needed. The degree covers not only the theoretical aspects of the field but also the practical side of bioinformatics, through contact with Hopkins faculty actively developing these technologies.

Program Committee
The program committee oversees the admissions, policy, and operations of the joint MS in Bioinformatics. The committee consists of the following members:

Richard McCarty, Co-Chair
William D. Gill Professor of Biology Emeritus, Dean Emeritus, and Chair
Center for Biotechnology Education
Zanvyl Krieger School of Arts and Sciences

Patrick Cummings, Co-Chair
Computer Science Program
Whiting School of Engineering

Kristina Obom
Director, Biotechnology and Bioinformatics
Center for Biotechnology Education
Advanced Biotechnology Studies
Advanced Academic Programs
Zanvyl Krieger School of Arts and Sciences

 Patrick Cummings
Director
Center for Biotechnology
Advanced Biotechnology Studies
Advanced Academic Programs
Zanvyl Krieger School of Arts and Sciences

Satyendra Kumar
EP Coordinator
Lead Research Engineer
Streamsage, Inc.

Eleanor Boyle Chlan
Computer Science Program
Whiting School of Engineering
Engineering for Professionals

Admission Requirements
Students entering this program must have completed a four-year bachelor’s degree in biological sciences or engineering, or a graduate degree in an appropriate field, with the following prerequisites required for admission to the program: two semesters of undergraduate Organic Chemistry or 410.302 Bio-Organic Chemistry; 410.601 Advanced Biochemistry; 605.201 Introduction to Programming Using Java, C++, or C; 605.202 Data Structures; an undergraduate or graduate course in Probability and Statistics or 410.645 Biostatistics; and Calculus. All the prerequisites can be taken in the existing Master of Science in Computer Science program or the Master of Science in Biotechnology program. Applicants must have a GPA of 3.0 or higher on a 4.0 scale in the latter half of their undergraduate or graduate studies. Applicants with less than the required GPA or who have not completed all the prerequisites may be admitted as provisional students. Applicants with a degree from a country other than the United States must provide credential evaluations and a TOEFL, with a minimum score of 100 on the Internet-based test.

This program is offered jointly by the Zanvyl Krieger School of Arts and Sciences (KSAS) and the Whiting School of Engineering. However, the administration is handled by KSAS, and applications for admission to the Master of Science in Bioinformatics program must be submitted directly to KSAS (bioinformatics.jhu.edu). In addition to supplying official transcripts, applicants must provide a résumé or curriculum vitae and a 500-word statement of purpose. The admissions committee reserves the right to request additional information from applicants, such as GRE scores or letters of recommendation, if needed to assess their candidacy for admission.
Bioinformatics

Program Structure
The joint MS degree will require certain prerequisites and a total of 11 courses. Students may elect to complete additional work and earn an MS in Bioinformatics with a thesis. The course offerings are listed below.

Prerequisites:
- Two semesters of Organic Chemistry (or 410.302 Bio-Organic Chemistry)
- One semester of Advanced Biochemistry (or 410.601 Advanced Biochemistry)
- Introduction to Programming Using Java, C++, or C (or 605.201 Introduction to Programming Using Java)
- Data Structures (or 605.202 Data Structures)
- One course in Probability and Statistics or (410.645 Biostatistics)
- Calculus

Core Courses—Five Required
410.602 Molecular Biology
410.610 Gene Organization and Expression

Select Either:
605.420 Algorithms for Bioinformatics OR
605.421 Foundations of Algorithms

Select Either:
605.441 Principles of Database Systems OR
410.634 Practical Computer Concepts for Bioinformatics

Select Either:
605.452 Biological Databases and Database Tools OR
410.633 Introduction to Bioinformatics

Concentration Courses—Choose Four
Students may choose any four of these courses:
605.443 The Semantic Web
605.451 Principles of Computational Biology
605.452 Biological Databases and Database Tools
605.453 Computational Genomics
605.456 Computational Drug Discovery and Development
605.716 Modeling and Simulation of Complex Systems
605.751 Computational Aspects of Molecular Structure
605.754 Analysis of Gene Expression and High-Content Biological Data
605.755 Systems Biology
410.635 Bioinformatics: Tools for Genome Analysis
410.639 Protein Bioinformatics
410.640 Phylogenetics and Comparative Genomics
410.661 Methods in Proteomics
410.666 Next-Generation DNA Sequencing and Analysis
410.671 Microarrays and Analysis
410.698 Bioperl
410.712 Advanced Practical Computer Concepts for Bioinformatics
410.713 Advanced Genomics and Genetics Analyses
410.754 Comparative Microbial Genomics: From Sequence to Significance

Notes: Students may take both 410.639 and 605.751. Students may take either 410.671 or 605.754, but not both.

Electives—Choose Two
Choose one elective from the approved list of computer science courses and one from the approved list of biotechnology courses.

Approved Computer Science Elective List
605.401 Foundations of Software Engineering
605.444 XML Design Paradigms
605.462 Data Visualization
605.481 Principles of Enterprise Web Development
605.484 Agile Development with Ruby on Rails
605.486 Mobile Application Development for the Android Platform
605.701 Software Systems Engineering
605.741 Distributed Database Systems: Cloud Computing and Data Warehouses
605.746 Machine Learning
605.747 Evolutionary Computation
605.759 Independent Project in Bioinformatics
605.782 Web Application Development with Java
605.787 Rich Internet Applications with Ajax
605.788 Big Data Processing Using Hadoop

Approved Biotechnology Elective List
410.603 Advanced Cell Biology I
410.604 Advanced Cell Biology II
410.612 Human Molecular Genetics
410.613 Principles of Immunology
410.615 Microbiology
410.616 Virology
410.622 Molecular Basis of Pharmacology
410.629 Genes and Disease
410.630 Gene Therapy
410.632 Emerging Infectious Diseases
410.638 Cancer Biology
410.641 Clinical and Molecular Diagnostics
410.648 Clinical Trial Design & Statistical Analysis
410.656 Recombinant DNA Laboratory
410.752 High-Throughput Screening and Automation Laboratory
410.800 Independent Research in Biotechnology
MS in Bioinformatics with Thesis Option

Students interested in pursuing the MS in Bioinformatics with the thesis are required to take 12 courses and should consult with the program advisor. The thesis is a two-semester research project. Students should take the following courses in consecutive semesters:

- 410.800 Independent Research in Biotechnology
- 410.801 Biotechnology Thesis

Bioinformatics—Online

Students may complete the Master of Science in Bioinformatics online, and all students may take advantage of online offerings. While not all courses are available online, a complete program is offered and additional online courses are continually being developed. This increases the flexibility of course offerings for students wishing to pursue studies in either the face-to-face or online format, or a combination of both.

Course content is identical to that in the face-to-face offerings but available in a paced, asynchronous mode over the Internet. Recorded lectures with associated multimedia content, are augmented with online discussions and weekly synchronous office hours. Prospective and current students should consult the KSAS website for the current online course offerings, course schedules, and procedures for online programs.

Course Descriptions

410.302 Bio-Organic Chemistry

This course provides a foundation in structural organic chemistry, acid base chemistry, chemical thermodynamics, and reaction mechanisms. Subjects include Lewis structures, atomic and hybridized orbitals, stereochemistry, inter- and intramolecular forces of attraction, nucleophilic reaction mechanisms, functional groups, and the organic chemistry of biological molecules.

Prerequisites
Two semesters of college chemistry.

Course Notes
Not for graduate credit.

Instructor: Staff
Online Option Available

410.601 Advanced Biochemistry

This course explores the roles of essential biological molecules including proteins, lipids, and carbohydrates, with an introduction to nucleic acids. It provides a systematic and methodical application of general and organic chemistry principles. Students examine the structure of proteins, their function, the methodologies for the purification and characterization of proteins, and the alteration of protein function through protein engineering. Enzymes and their kinetics and mechanisms are covered in detail. This course provides the linkage between the inanimate world of chemistry and the living world of biology.

Instructor: Staff
Online Option Available

410.602 Molecular Biology

This course provides a comprehensive overview of the key concepts in molecular biology. Topics include nucleic acid structure and function, DNA replication, transcription, translation, chromosome structure and remodeling, and regulation of gene expression in prokaryotes and eukaryotes. Extended topics include methods in recombinant DNA technology, micro-arrays, and microRNA.

Prerequisites
410.601 Advanced Biochemistry.

Instructor: Ma
Online Option Available

410.603 Advanced Cell Biology I

This course covers cell organization and subcellular structure. Students examine the evolution of the cell, chromosome and plasma membrane structures and behaviors, mechanics of cell division, sites of macromolecular synthesis and processing, transport across cell membranes, cell dynamics, organelle biogenesis, and cell specialization. Students also are introduced to

Courses from Other JHU Schools

There are various relevant courses related to bioinformatics at Homewood (Electrical Engineering and Biomedical Engineering departments) and at the Johns Hopkins Medical School or Bloomberg School of Public Health. On special request and in consultation with their advisors, students may take one or two of these courses as part of their programs, provided that the students meet the prerequisites and obtain instructor permission and the advisor approves the course as a suitable substitution for one of the requirements above. The course descriptions and offerings are provided on the websites of the respective schools.

Tuition

Tuition for the courses in the joint degree varies by course and school of origin and is posted in the Course Schedule each semester.

Facilities

The program uses facilities on the Homewood and Montgomery County campuses. These campuses contain numerous modern classrooms, teaching support equipment, computer laboratories, lounges, and food service and are supported by appropriate staff. Both locations can accommodate additional courses and students. Courses are sometimes offered at APL. An increasing number of courses are being offered online.
the experimental techniques used in cell biology to study cell growth, manipulation, and evaluation.

**Instructor:** Staff

**Online Option Available**

**410.604 Advanced Cell Biology II**

This course is a continuation of 410.603 Advanced Cell Biology I and further explores cell organization and subcellular structure. Students examine cell-to-cell signaling that involves hormones and receptors, signal transduction pathways, second messenger molecules, cell adhesion, extracellular matrix, cell cycle, programmed cell death, methylation of DNA and modification of chromatic structure, and mechanisms of the cell. The involvement of abnormalities in signal transduction pathways to oncogenesis and other disease states will be stressed. Where appropriate, current drugs and developing techniques will be examined in the context of relevant pathological states.

**Instructor:** Staff

**Online Option Available**

**410.610 Gene Organization and Expression**

Students use genetic analysis and molecular biology techniques to investigate chromosome organization, chromatin structure, function genomics, and mechanisms of differential gene expression. Other topics include DNA methylation, silencers, enhancers, genomic imprinting, and micro-array analyses.

**Instructor:** Staff

**Online Option Available**

**410.612 Human Molecular Genetics**

In this course, students learn to use the tools of modern genomics to elucidate phenotypic variation within populations. The course uses human disease (from simple Mendelian disorders to common complex disorders) to exemplify the types of studies and tools that can be used to characterize cellular pathophysiology as well as to provide genetic diagnostics and therapies. Students become facile with linkage analysis, cancer genetics, microarray analysis (oligo and cDNA arrays), gene therapy, SNP studies, imprinting, disequilibrium mapping, and ethical dilemmas associated with the Human Genome Project.

**Instructor:** Staff

**Online Option Available**

**410.613 Principles of Immunology**

This course covers molecular and cellular immunology, including antigen and antibody structure and function, effector mechanisms, complement, major histocompatibility complexes, B- and T-cell receptors, antibody formation and immunity, cytotoxic responses, and regulation of the immune response. Students are also introduced to the applied aspects of immunology, which include immunoassay design, various formats and detection methods, and flow cytometry. Special topics include organ transplantation, immunosuppression, immunotherapy, autoimmunity, and DNA vaccination.

**Instructor:** Staff

**Online Option Available**

**410.615 Microbiology**

This course is an overview of microorganisms important in clinical diseases and biotechnology. Students are introduced to the general concepts concerning the morphology, genetics, and reproduction of these microbial agents. Lectures focus on individual organisms with emphasis on infectious diseases, biotechnology applications, molecular and biochemical characteristics, and molecular and serological identification methods. Students will also discuss the impact that biotechnology, and particularly genomics, will have on the development of antibiotics and vaccines as treatment and preventive measures.

**Instructor:** Staff

**Online Option Available**

**410.616 Virology**

This course covers the advanced study of viruses with regard to the basic, biochemical, molecular, epidemiological, clinical, and biotechnological aspects of animal viruses primarily and bacteriophage, plant viruses, viroids, prions, and unconventional agents secondarily. Specific areas of virology, including viral structure and assembly, viral replication, viral recombination and evolution, virus-host interactions, viral transformation, gene therapy, antiviral drugs, and vaccines, are presented. The major animal virus families are discussed individually with respect to classification, genomic structure, virion structure, virus cycle, pathogenesis, clinical features, epidemiology, immunity, and control. The viral vectors and their applications in biotechnology are discussed.

**Instructor:** Staff

**Online Option Available**

**410.622 Molecular Basis of Pharmacology**

This course begins by reviewing receptor binding and enzyme kinetics. Various cellular receptors and their physiology are discussed as well as the pharmacological agents used to define and affect the receptor's function. Students study the pharmacology of cell surface receptors and intracellular receptors. Also considered are the drugs that affect enzymes.

**Instructor:** Staff

**Online Option Available**

**410.629 Genes and Disease**

Because of recent advances, powerful diagnostic tests now detect genetic diseases, and there is promise of gene replacement therapy. In this course, students cover general genetic principles, DNA tools for genetic analysis, cytogenetics, gene mapping, the molecular basis of genetic diseases, animal models, immunogenetics, genetics of development, genetics of
cancer, and treatment of genetic diseases. Molecular methods of analysis are emphasized.

**Instructor:** Staff

Online Option Available

**410.630  Gene Therapy**

Students are introduced to gene transfer, its technical evolution, and its testing through clinical studies. Gene therapy holds promise for both genetic diseases and acquired diseases such as cancer and AIDS. The health, safety, and ethical issues surrounding gene therapy are discussed, together with the review and oversight systems established to regulate this therapy. Students also consider how industry is developing these techniques, both in new start-up companies as well as in established biotechnology and pharmaceutical companies. An overview of proprietary and patent issues in gene therapy is part of the course.

**Instructor:** Staff

Online Option Available

**410.632  Emerging Infectious Diseases**

This course focuses on emerging infectious diseases from many different perspectives. The maladies addressed range from diseases that have reappeared in altered genetic forms such as the influenza virus and the West Nile virus to the lethal hemorrhagic fever caused by the Ebola virus. Also discussed is the threat of recombinant and ancient infectious agents such as Bacillus anthracis, causative agent of anthrax, which can be used in biological warfare weapons. Opinions from noted scientists and leaders concerning emerging diseases and the prospects for battling them successfully provide scientific and social perspective.

**Instructor:** Staff

Online Option Available

**410.633  Introduction to Bioinformatics**

Retrieval and analysis of electronic information are essential in today's research environment. This course explores the theory and practice of biological database searching and analysis. In particular, students are introduced to integrated systems where a variety of data sources are connected through World Wide Web access. Information retrieval, as well as interpretations that are discussed, and many practical examples in a computer laboratory setting enable students to improve their data mining skills. Methods included in the course are searching the biomedical literature, sequence homology searching and multiple alignment, protein sequence motif analysis, and several genome analytical methods. Classes are held in a computer laboratory. Acquaintance with computers is required.

**Instructor:** Staff

Online Option Available

**410.634  Practical Computer Concepts for Bioinformatics**

This course introduces students with a background in the life sciences to the basic computing concepts of the UNIX operating system, relational databases, structured programming, object-oriented programming, and the Internet. Included is an introduction to SQL and the Perl scripting language. The course emphasizes relevance to molecular biology and bioinformatics. It is intended for students with no computer programming background but with a solid knowledge of molecular biology.

**Instructor:** Staff

Online Option Available

**410.635  Bioinformatics: Tools for Genome Analysis**

Several large-scale DNA sequencing efforts have resulted in mega-base amounts of DNA sequences being deposited in public databases. As such, the sequences are of less use than those sequences that are fully annotated. To assign annotations such as exon boundaries, repeat regions, and other biologically relevant information accurately in the feature tables of these sequences requires a significant amount of human intervention. This course instructs students on computer analytical methods for gene identification, promoter analysis, and introductory gene expression analysis using software methods. Additionally, students are introduced to comparative genomics and proteomic analysis methods. Students will become proficient in annotating large genomic DNA sequences. Students complete two large sequence analysis projects during the course.

**Instructor:** Staff

Online Option Available

**410.638  Cancer Biology**

This course provides students with knowledge of the fundamental principles of the molecular and cellular biology of cancer cells. Lectures and demonstrations explain the role of growth factors, oncogenes, tumor suppressor genes, angiogenesis, and signal transduction mechanisms in tumor formation. Discussion of aspects of cancer epidemiology, prevention, and principles of drug action in cancer management is part of the course.

**Instructor:** Staff

Online Option Available

**410.639  Protein Bioinformatics**

Because the gap between the number of protein sequences and the number of protein crystal structures continues to expand, protein structural predictions are increasingly more important. This course provides a working knowledge of various computer-based tools available for predicting the structure and function of proteins. Topics include protein database searching, protein physicochemical properties, secondary structure prediction, and statistical verification. Also covered are graphic visualization of the different types of three-dimen-
sional (3D) folds and predicting 3D structures by homology. Computer laboratories complement material presented in lectures.

**Instructor:** Staff

Online Option Available

**410.640 Phylogenetics and Comparative Genomics**

This course will provide a practical, hands-on introduction to the study of phylogenetics and comparative genomics. Theoretical background on molecular evolution will be provided only as needed to inform the comparative analysis of genomic data. The emphasis of the course will be placed squarely on the understanding and use of a variety of computational tools designed to extract meaningful biological information from molecular sequences. Lectures will provide further information on the conceptual essence of the algorithms that underlie various sequence analysis tools, as well as the rationale behind their use. Only programs that are freely available, as either downloadable executables or as web servers, will be used in this course. Students will be encouraged to use the programs and approaches introduced in the course to address questions relevant to their own work.

**Instructor:** Staff

Online Option Available

**410.641 Clinical and Molecular Diagnostics**

This course covers basic concepts and practical applications of modern laboratory diagnostic techniques. Topics include the principles of testing methodology, quality assurance, and the application of molecular methods to the clinical and research laboratory. The test methods to be covered include nucleic acid–based methods such as hybridization, amplification, and sequencing; non-nucleic acid methods such as HPLC, GLC, and protein analysis; and technologies such as PFGE, ribotyping, RFLP, and microarrays. In addition to learning about the test procedures, students are exposed to aspects of statistics, quality control, regulatory issues, and applications of these methods to the diagnosis and prognosis of human disease.

**Prerequisites**

410.601 Biochemistry; 410.602 Molecular Biology.

**Instructor:** Staff

Online Option Available

**410.645 Biostatistics**

This course introduces statistical concepts and analytical methods as applied to data encountered in biotechnology and biomedical sciences. It emphasizes the basic concepts of experimental design, quantitative analysis of data, and statistical inferences. Topics include probability theory and distributions; population parameters and their sample estimates; descriptive statistics for central tendency and dispersion; hypothesis testing and confidence intervals for means, variances, and proportions; the chi-square statistic; categorical data analysis; linear correlation and regression model; analysis of variance; and nonparametric methods. The course provides students a foundation to evaluate information critically to support research objectives and product claims and a better understanding of statistical design of experimental trials for biological products/devices.

**Prerequisites**

Basic mathematics (algebra); scientific calculator needed.

**Instructor:** Staff

Online Option Available

**410.648 Clinical Trial Design & Statistical Analysis**

Through a case study approach, this course will cover the basic design issues of clinical trials. The design of specific trials will be studied to illustrate the major issues in the design of these studies, such as end point definition, control group selection, and eligibility criteria. The course also covers the analysis of these studies, including approaches that are central to clinical trials, such as stratified analysis, adjustment factors, and “intention-to-treat” analyses. The analytical techniques to be covered will include the analysis of correlated data (i.e., clustered data, longitudinal data), survival analysis using the proportional hazards (Cox) regression model, and linear models. The course will also cover various aspects of statistical computing, including organizing data, data management, and performing analyses using computer software. The ethical reporting of clinical trial results will also be covered with reference to the medical research literature.

**Prerequisites**

410.651 Clinical Development of Drugs and Biologics, 410.645 Biostatistics (or equivalent).

**Instructor:** Staff

Online Option Available

**410.656 Recombinant DNA Laboratory**

This laboratory course introduces students to methods for manipulating and analyzing nucleic acids. Students gain extensive hands-on experience with plasmid purification, restriction mapping, ligations, bacterial transformations, and gel electrophoresis, as well as applications of the polymerase chain reaction. This course is not recommended for students with substantial experience in these methodologies.

**Prerequisites**

410.601 Advanced Biochemistry and 410.602 Molecular Biology.

**410.661 Methods in Proteomics**

This course covers the analytical methods used to separate and characterize pharmaceutical compounds (predominantly proteins) derived through biotechnology. While emphasis is placed on the general principles and applicability of the methods, current protocols are discussed, and problem sets representing realistic developmental challenges are assigned. Topics include chromatography (HPLC, SEC, IEC), electrophoretic techniques (2D gelelectrophoresis), spectroscopic methods
(UV/Vis, Fluorescence, CD), analytical ultra-centrifugation, micro-arrays, mass spectroscopy, amino acid analysis, sequencing, and methods to measure protein-protein interactions.

**Instructor:** Staff

Online Option Available

**410.666 Next-Generation DNA Sequencing and Analysis**

The recent revolution in DNA sequencing technologies has transformed biology within a few short years, dropping the cost and ease of sequencing dramatically to the point where the “$1,000 Human Genome” is in sight. Armed with complete genome sequences, biologists need to identify the genes encoded within the sequences as well as the variation in these genes between individuals, assign functions to the genes, and put the genes into functional and metabolic pathways. This course will provide an overview of next-generation sequencing technologies in the historical context of DNA sequencing, the pros and cons of each technology, and the bioinformatics techniques used with this sequence information, beginning with quality control assessment, genome assembly, and annotation.

**Prerequisites**


**Instructor:** Staff

**410.671 Microarrays and Analysis**

This course will focus on the analysis and visualization of microarray data. The general aim is to introduce students to the various techniques and issues involved with analyzing gene expression data and to visualize the results using modern statistical scripting software. Topics include detecting and attributing sources of data variability, assessing sample size and power, identifying differentially expressed genes with relevant statistical tests, and controlling for false positive discovery. An introduction to linear and nonlinear dimensionality reduction methods, pattern recognition (clustering), and supervised classification techniques will be covered. Assignments and concepts will make use of real experimental data sets from platforms such as Affymetrix, Agilent, Illumina, and custom cDNA. Analysis will be conducted in R using Bioconductor packages, with applications focused on target identification, biomarker discovery, pathogen detection, and many others.

**Instructor:** Staff

Online Option Available

**410.698 Bioperl**

This course builds on the Perl concepts taught in 410.634 Practical Computer Concepts for Bioinformatics. Perl has emerged as the language of choice for the manipulation of bioinformatics data. Bioperl, a set of object-oriented modules that implements common bioinformatics tasks, has been developed to aid biologists in sequence analysis. The course will include an overview of the principal features of Bioperl and give students extensive opportunity to use Perl and the tools of Bioperl to solve problems in molecular biology sequence analysis.

**Instructor:** Staff

Online Option Available

**410.712 Advanced Practical Computer Concepts for Bioinformatics**

This intermediate- to advanced-level course, intended as a follow-on to 410.634 Practical Computer Concepts for Bioinformatics (a prerequisite for this new class), will integrate and expand on the concepts from that introductory class to allow students to create working, web-based bioinformatics applications in a project-based course format. After reviewing the concepts covered in 410.634, students will learn how to create functional web applications on a UNIX system, using Perl and CGI to create forms that can be acted on, and using the Perl DBI module to interface with MySQL relational databases that they will create and populate to retrieve and present information. This will be demonstrated by building an in-class, instructor-led project. More advanced SQL concepts and database modeling will also be covered, and the course will include a brief introduction to the PHP scripting language. Class time in the latter weeks of the class will be devoted to individual assistance on student projects as well as to short lectures on advanced Perl topics, object-oriented Perl, and installing Perl modules. The last two weeks will be devoted to student presentations and a peer critique of their projects. Once again, whenever possible, this course will emphasize relevance to solving problems in molecular biology and bioinformatics.

**Prerequisites**

410.601 Advanced Biochemistry, 410.602 Molecular Biology, 410.634 Practical Computer Concepts for Bioinformatics with a grade of A– or above or permission of associate program chair.

Online Option Available

**410.713 Advanced Genomics and Genetics Analyses**

The next generation of array and sequencing technologies provides the ability to investigate large quantities of genomics information with higher sensitivity, greater throughput, and lower costs. This also introduces new challenges in data management, novel algorithmic approaches, and general interpretation. This course builds on the topics in 410.671 Microarrays and Analysis to address analysis of both genetic variation and genomics content using technologies measuring splice variants, single-nucleotide polymorphisms (SNPs), copy number variation (CNV), and transcription factor binding sites. Analysis methods for deep sequencing technologies are also introduced, including quantitative mRNA content (RNA-Seq) and whole-genome assembly methods with de novo and reference-based approaches.

**Prerequisites**

Bioinformatics core courses and 410.671 Microarrays and Analysis.
410.752  **High-Throughput Screening and Automation Laboratory**

This course will utilize hands-on instruction in automated bioassay systems for high-throughput screening (HTS) as an entry point to covering pertinent aspects of HTS, such as data manipulation, storage, and analysis; liquid handling robotics; microtiter plate washing, manipulation, and bar coding; HTS assay detectors; and automated devices for assay setup, validation, and visualization. Cost considerations, HTS amenable assay systems, and miniaturization and scale-up will also be discussed.

**Prerequisites**
All four core courses and 410.696 Bioassay Development.

410.754  **Comparative Microbial Genomics: From Sequence to Significance**

Hundreds of bacterial and Archaeal genomes have been completely sequenced, and thousands more will follow in the near future. In this course, students will learn how to make sense of this vast sea of information in order to understand the diversity of microbial life on earth: transforming DNA data into knowledge about the metabolism, biological niche, and lifestyle of these organisms. The use and development of bioinformatic platforms for the sensible comparison of genetic function and context are essential for work in modern microbiology. Topics covered will include methods for sequencing, gene finding, functional prediction, metabolic pathway and biological system reconstruction, phylogenomics, ontologies, and high-throughput functional genomics. Particular attention will be paid to publicly available bioinformatics resources and their proper use. Examples will be drawn from microbes of importance to human health, industry, ecology, agriculture, and biodefense. Lectures and discussions are integrated with computer exercises where appropriate.

**Prerequisites**

**Instructor:** Staff

410.800  **Independent Research in Biotechnology**

Students in the biotechnology program have the opportunity to enroll in an independent research course. This elective course is an option after a student has completed at least eight graduate-level courses and has compiled a strong academic record. Prior to proposing a project, an interested student must have identified a research topic and a mentor who is familiar with the prospective inquiry and who is willing to provide guidance and oversee the project. The research project must be independent of current work-related responsibilities as determined by the project mentor. The mentor may be a faculty member teaching in the biotechnology program, a supervisor from the student’s place of work, or any expert with appropriate credentials. Students are required to submit a formal proposal for review and approval by the biotechnology program committee. The proposal must be received by the Advanced Academic Programs (AAP) office no later than one month prior to the beginning of the term in which the student wants to enroll in the course. Students must meet with a member of the program committee periodically for discussion of the project's progress, and a written document must be completed and approved by the program committee and project mentor for the student to receive graduate credit. Additional guidelines can be obtained from the AAP administrative office.

**Prerequisites**
All four core courses and four elective courses.

410.801  **Biotechnology Thesis**

Students wishing to complete a thesis may do so by embarking on a two-semester thesis project, which includes 410.800 Independent Research in Biotechnology and 410.801 Biotechnology Thesis. This project must be a hypothesis-based original research study. The student must complete 410.800 Independent Research in Biotechnology and fulfill the requirements of that course, including submission of project proposal, final paper, and poster presentation, before enrolling in the subsequent thesis course. For the thesis course, students are required to submit a revised proposal (an update of the 410.800 Independent Research in Biotechnology proposal) for review and approval by the faculty advisor and biotechnology program committee one month prior to the beginning of the term. Students must meet the faculty advisor periodically for discussion of the project’s progress. Graduation with a thesis is subject to approval by the thesis committee and program committee and requires students to present their projects to a faculty committee both orally and in writing.

**Prerequisites**
All four core science courses and six elective courses, which must include 410.800 Independent Research in Biotechnology and 410.645 Biostatistics.

**Course Notes**

- **Thesis Guidelines:** If a student works on sponsored research, the thesis advisor (or sponsoring institution) and the student should sign a letter of agreement on publication rights and authorship before work on the thesis begins. Research expenses, such as lab supplies, related travel, and services essential to the collecting and processing of data, are paid for by the thesis advisor or sponsoring organization. Special costs of thesis production, such as typing, art work, and duplicating of the thesis, are the student’s responsibility.

- **Thesis Format:** The student must follow the university’s “Guidelines for the Preparation of Dissertations and Theses,” to ensure thesis acceptance. The guidelines are available at library.jhu.edu/services/cbo/guidelines.html.

- **Thesis Committee:** The thesis committee includes the thesis advisor (mentor), faculty advisor, and a member of the program committee (or their designate).
605.201 Introduction to Programming Using Java

This course enables students without a background in software development to become proficient programmers who are prepared for a follow-on course in data structures. The Java language will be used to introduce foundations of structured, procedural, and object-oriented programming. Topics include I/O, data types, operators, operands, expressions, conditional statements, iteration, recursion, arrays, functions, parameter passing, and returning values. Students will also be introduced to classes, objects, object references, inheritance, polymorphism, and exception handling. Additional topics include file I/O, searching, sorting, Java Collections, and an introduction to Applets. Students will complete several programming assignments to develop their problem-solving skills and to gain experience in detecting and correcting software errors.

Prerequisites
One year of college mathematics.

Course Notes
Not for graduate credit.

Instructors: Chittargi, Ferguson, Qie, Shyamsunder, Smith

605.202 Data Structures

This course investigates abstract data types (ADTs), recursion, algorithms for searching and sorting, and basic algorithm analysis. ADTs to be covered include lists, stacks, queues, priority queues, trees, sets, and dictionaries. The emphasis is on the tradeoffs associated with implementing alternative data structures for these ADTs. There will be four or five substantial Java programming assignments.

Prerequisites
One year of college mathematics. 605.201 Introduction to Programming Using Java or equivalent.

Course Notes
Not for graduate credit.

Instructors: Chlan, Kann, Resch, Tjaden

Online Option Available

605.420 Algorithms for Bioinformatics

This follow-on course to data structures (e.g., 605.202) provides a survey of computer algorithms, examines fundamental techniques in algorithm design and analysis, and develops problem-solving skills required in all programs of study involving computer science. Topics include advanced data structures (red-black and 2-3-4 trees, union-find), algorithm analysis and computational complexity (recurrence relations, big-O notation, introduction to NP-completeness), sorting and searching, design paradigms (divide and conquer, greedy heuristic, dynamic programming), and graph algorithms (depth-first and breath-first search, minimum spanning trees). Advanced topics are selected from among the following: multithreaded algorithms, matrix operations, linear programming, string matching, computational geometry, and approximation algorithms. The course will draw on applications from Bioinformatics. This course does not satisfy the foundation course requirement for Computer Science or Cybersecurity. Students cannot earn credit for both 605.420 and 605.421.

Prerequisites
605.202 Data Structures or equivalent. 605.203 Discrete Mathematics or equivalent is recommended.

Instructor: Chlan

Online Option Available

605.421 Principles of Database Systems

This course examines the underlying concepts and theory of database management systems. Topics include database system architectures, data models, query languages, conceptual and logical database design, physical organization, and transaction management. The entity-relationship model and relational model are investigated in detail, object-oriented databases are introduced, and legacy systems based on the network and hierarchical models are briefly described. Mappings from the conceptual level to the logical level, integrity constraints, dependencies, and normalization are studied as a basis for formal design. Theoretical languages such as the relational algebra and the relational calculus are described, and high-level languages such as SQL and QBE are discussed. An overview of file organization and access methods is provided as a basis for discussion of heuristic query optimization techniques. Finally, transaction processing techniques are presented with a specific emphasis on concurrency control and database recovery.

Instructors: Kang, Liu

Online Option Available

605.421 Foundations of Algorithms

This follow-on course to data structures (e.g., 605.202) provides a survey of computer algorithms, examines fundamental techniques in algorithm design and analysis, and develops problem-solving skills required in all programs of study involving computer science. Topics include advanced data structures (red-black and 2-3-4 trees, union-find), recursion and mathematical induction, algorithm analysis and com-
Bioinformatics

Computational complexity (recurrence relations, big-O notation, NP-completeness), sorting and searching, design paradigms (divide and conquer, greedy heuristic, dynamic programming, amortized analysis), and graph algorithms (depth-first and breadth-first search, connectivity, minimum spanning trees, network flow). Advanced topics are selected from among the following: randomized algorithms, information retrieval, string and pattern matching, and computational geometry.

Prerequisites
605.202 Data Structures or equivalent. 605.203 Discrete Mathematics or equivalent is recommended.

Instructor: Boon, Leu, Maurer, Rodriguez, Sadowsky, Sheppard

Online Option Available

605.443 The Semantic Web
The Semantic Web is an activity by the WWW Consortium to create a large set of XML-based languages, along with information on how various tags relate to real-world objects and concepts. This course covers Semantic Web technologies, including RDF (Resource Description Format, a structure for describing and interchanging metadata on the web) and OWL (Web Ontology Language), with domain-specific standards and ontologies (formal specifications of how to represent objects and concepts). Representative applications of RDF, OWL, and ontologies will be discussed. Students will complete a Semantic Web project in an application area of interest to them. Examples will be drawn from several application areas.

Prerequisites
605.444 XML Design Paradigms or equivalent.

Course Notes
This course may be counted toward a three-course track in Bioinformatics.

Instructor: Cott

Online Option Available

605.444 XML Design Paradigms
The course explores understanding the tradeoffs among XML grammars and XML techniques to solve different classes of problems. Topics include optimization of XML grammars for different XML technologies; benefits of using different XML schema languages; tradeoffs in using different parsing approaches; benefits of parsing technology vs. XML query; the role of Web 2.0 to deliver functionality through various web services approaches; exploiting XML to drive audio, visual, and tactile displays; the role of XML in multiplying the power of standard web browser technologies; and the role of Web 3.0 to deliver Semantic Web functionality. XML technologies that will be covered include XML Schema, XPath, XSLT, SAX, DOM, XQuery, SOAP, WSDL, JAX-B, JAX-WS, REST, RDF, and OWL.

Prerequisites
605.481 Principles of Enterprise Web Development or equivalent Java experience.

Course Notes
Formerly 635.444 XML: Technology and Applications.

Instructors: Chittangi, Silverberg

Online Option Available

605.451 Principles of Computational Biology
This course is an interdisciplinary introduction to computational methods used to solve important problems in DNA and protein sequence analysis. The course focuses on algorithms but includes material to provide the necessary biological background for science and engineering students. Algorithms to be covered include dynamic programming for sequence alignment, such as Smith-Waterman, FASTA, and BLAST; hidden Markov models, such as the forward, Viterbi, and expectation maximization algorithms; a range of gene-finding algorithms; phylogenetic tree construction; and clustering algorithms.

Prerequisites
Familiarity with probability and statistics; working knowledge of Java, C++, or C; 605.205 Molecular Biology for Computer Scientists or a course in molecular biology; and either a course in cell biology or biochemistry.

Instructors: Przytycka and Rogozin, Qie

605.452 Biological Databases and Database Tools
The sequencing of the human genome and intense interest in proteomics and molecular structure have resulted in an explosive need for biological databases. This course surveys a wide range of biological databases and their access tools and enables students to develop proficiency in their use. Databases introduced include genome and sequence databases such as GenBank and Ensemble, as well as protein databases such as PDB and SWISS-PROT. Tools for accessing and manipulating sequence databases such as BLAST, multiple alignment, Perl, and gene-finding tools are covered. Specialized databases such as KEGG and HapMap are surveyed for their design and use. The course also focuses on the design of biological databases and examines issues related to heterogeneity, interoperability, complex data structures, object orientation, and tool integration. Students will create their own small database as a course project and will complete homework assignments using biological databases and database tools.

Prerequisites
605.205 Molecular Biology for Computer Scientists or equivalent. 605.441 Principles of Database Systems or 410.634 Practical Computer Concepts for Bioinformatics recommended.

Instructor: Hobbs

Online Option Available

605.453 Computational Genomics
This course focuses on current problems of computational genomics. Students will explore bioinformatics software, discuss bioinformatics research, and learn the principles underlying a variety of bioinformatics algorithms. The emphasis is on
algorithms that use probabilistic and statistical approaches. Topics include analyzing eukaryotic, bacterial, and viral genes and genomes, genome sequencing and assembling, finding genes in genomes and identifying their biological functions, predicting regulatory sites, and assessing gene and genome evolution.

**Prerequisites**

605.205 Molecular Biology for Computer Scientists or equivalent and familiarity with probability and statistics.

**Instructor:** Ermolaeva

**Online Option Available**

605.456 **Computational Drug Discovery and Development**

Recent advances in bioinformatics and drug discovery platforms have brought us significantly closer to the realization of rational drug design and development. Across the pharmaceutical industry, considerable effort is being invested in developing experimental and translational medicine, and it is starting to make a significant impact on the drug discovery process itself. This course examines the major steps of the evolving modern drug discovery platforms, the computational techniques and tools used during each step of rational drug discovery, and how these techniques facilitate the integration of experimental and translational medicine with the discovery/development platforms. The course will build on concepts from a number of areas including bioinformatics, computational genomic/proteomics, in silico system biology, computational medicinal chemistry, and pharmaceutical biotechnology. Topics covered in the course include comparative pharmacogenomics, protein/antibody modeling, interaction and regulatory networks, QSAR/pharmacophores, ADME/toxicology, and clinical biomarkers. Relevant mathematical concepts are developed as needed in the course.

**Prerequisites**

605.205 Molecular Biology for Computer Scientists or equivalent.

**Instructor:** Kumar

**Online Option Available**

605.462 **Data Visualization**

This course explores the underlying theory and practical concepts in creating visual representations of large amounts of data. It covers the core topics in data visualization: data representation, visualization toolkits, scientific visualization, medical visualization, information visualization, flow visualization, and volume rendering techniques. The related topics of applied human perception and advanced display devices are also introduced.

**Prerequisites**

Experience with data collection/analysis in data-intensive fields or background in computer graphics (e.g., 605.467 Computer Graphics) is recommended.

**Instructor:** Chlan

605.481 **Principles of Enterprise Web Development**

This course examines three major topics in the development of applications for the World Wide Web. The first is website development using HTML and related standards. The second is the implementation of client-side applications using the Java programming language, including user interface development, asynchronous event handling, multithreaded programming, and network programming. Distributed object protocols via RMI or CORBA and distributed database access via JDBC may also be introduced. The third topic is the design of server-side web applications, for which students will examine the underlying web protocol (HTTP), the development of client-side interfaces (e.g., via HTML forms), and the implementation of server-side programs (e.g., via Java servlets or traditional CGI).

**Instructors:** Chittargi, R. Evans, Shyamsunder, Spiegel

**Online Option Available**

605.484 **Agile Development with Ruby on Rails**

Modern web applications are expected to facilitate collaboration, with user participation being a significant facet of the system. Components such as wikis, blogs, and forums are now commonplace. While feature sets continue to expand, there is continuing pressure to develop and deploy capabilities more quickly to enable organizations to remain competitive. This pressure has led to the development of languages and frameworks geared toward rapid prototyping, with Ruby on Rails being the most popular. Ruby on Rails is a model-view-controller (MVC) framework that enables efficient application development and deployment. Techniques such as convention over configuration and object-relational mapping with ActiveRecord along with enhanced AJAX support offer a simple environment with significant productivity gains. This code-intensive course introduces Ruby on Rails, the patterns it implements, and its applicability to the rapid development of collaborative applications.

**Prerequisites**

605.481 Principles of Enterprise Web Development or equivalent.

**Instructor:** Hazins

**Online Option Available**

605.486 **Mobile Application Development for the Android Platform**

This project-oriented course will investigate the issues surrounding application development for mobile platforms. First, we will look at techniques for building applications that adapt to the ways in which mobile apps differ from traditional desktop or web-based apps: constrained resources, small screen sizes, varying display resolutions, intermittent network connectivity, specialized sensors, security restrictions, and so forth. Second, we will look at best practices for making mobile applications flexible: using XML-based layouts, managing multimedia, storing user data, networking via Bluetooth and WiFi, determining device location and orientation,
deploying applications, and gracefully handling shutdowns and restarts to the application. Optional topics may include embedding web components with WebKit, showing maps with the Google Maps plug-in, and storing local data with SQLite. Students will be provided links to download free tools for building and testing Android apps; there is no requirement that students own a physical Android device.

**Prerequisites**
605.481 Principles of Enterprise Web Development or equivalent Java experience.

**Instructor:** Stanchfield

### 605.716 Modeling and Simulation of Complex Systems

This course focuses on the application of modeling and simulation principles to complex systems. A complex system is a large-scale nonlinear system consisting of interconnected or interwoven parts (such as a biological cell, the economy, or an ecological system). The course begins with an overview of complex systems, followed by modeling and simulation techniques based on nonlinear differential equations, networks, stochastic models, cellular automata, and swarm-like systems. Existing software systems will be used to illustrate systems and provide practical experience. During the semester, each student will complete a modeling project of a complex system. While this course is intended for computer science or engineering students interested in modeling any complex system, it may also be taken by bioinformatics students interested in modeling complex biological systems. Students interested in bioinformatics will study a parallel track exposing them to existing whole-cell modeling tools such as E-Cell, COPASI, and BioSpice.

**Prerequisites**
Knowledge of elementary probability and statistics and previous exposure to differential equations. Students applying this course to the MS in Bioinformatics should also have completed at least one Bioinformatics course prior to enrollment.

**Course Notes**
This course may be counted toward a three-course track in Bioinformatics.

**Instructor:** Weisman

### 605.741 Distributed Database Systems: Cloud Computing and Data Warehouses

This course investigates the architecture, design, and implementation of massive-scale data systems. The course discusses foundational concepts of distributed database theory including design and architecture, security, integrity, query processing and optimization, transaction management, concurrency control, and fault tolerance. It then applies these concepts to both large-scale data warehouse and cloud computing systems. The course blends theory with practice, with each student developing both distributed database and cloud computing projects.

**Prerequisites**
605.441 Principles of Database Systems and 605.481 Principles of Enterprise Web Development or equivalent knowledge of Java and HTML. Familiarity with “big-O” concepts and notation is recommended

**Course Notes**
Formerly 605.741 Distributed Database Systems.

**Instructor:** Silberberg

Online Option Available

### 605.746 Machine Learning

How can machines improve with experience? How can they discover new knowledge from a variety of data sources? What computational issues must be addressed to succeed? These are questions that are addressed in this course. Topics range from determining appropriate data representation and models for learning, understanding different algorithms for knowledge and model discovery, and using sound theoretical and experimental techniques in assessing performance. Specific approaches covered include statistical techniques (e.g., k-nearest neighbor and Bayesian learning), logical techniques (e.g., decision tree and rule induction), function approximation (e.g., neural networks and kernel methods), and reinforcement learning. The topics are discussed in the context of current machine learning and data mining research. Students will participate in seminar discussions and will complete and present the results of an individual project.

**Prerequisites**
605.445 Artificial Intelligence is recommended but not required.

**Instructor:** Sheppard

Online Option Available

### 605.747 Evolutionary Computation

Recently, principles from the biological sciences have motivated the study of alternative computational models and approaches to problem solving. This course explores how principles from theories of evolution and natural selection can be used to construct machines that exhibit nontrivial behavior. In particular, the course covers techniques from genetic algorithms, genetic programming, and artificial life for developing software agents capable of solving problems as individuals and as members of a larger community of agents. Specific topics addressed include representation and schemata; selection, reproduction, and recombination; theoretical models of evolutionary computation; optimal allocation of trials (i.e., bandit problems); search, optimization, and machine learning; evolution of programs; population dynamics; and emergent behavior. Students will participate in seminar discussions and will complete and present the results of an individual project.

**Prerequisites**
605.445 Artificial Intelligence is recommended but not required.

**Instructor:** Sheppard

Online Option Available
605.751  Computational Aspects of Molecular Structure

This course focuses on computational methods for studying protein and RNA structure, protein-protein interactions, and biological networks. Algorithms for prediction of RNA secondary structure, protein-protein interactions, and annotation of protein secondary/tertiary structure and function are studied in depth. Students will apply various computer programs and structure-visualization software to secondary and tertiary protein structure prediction, structure-structure comparison, protein domain classification, annotation of functionally important sites, and protein design. Interesting aspects of protein interaction and metabolic networks are also discussed.

Prerequisites

605.205 Molecular Biology for Computer Scientists or equivalent. 605.451 Principles of Computational Biology is recommended.

Instructors: Przytycka and Panchenko

605.754  Analysis of Gene Expression and High-Content Biological Data

The development of microarray technology, rapid sequencing, protein chips, and metabolic data has led to an explosion in the collection of “high-content” biological data. This course explores the analysis and mining of gene expression data and high-content biological data. A survey of gene and protein arrays, laboratory information management systems, data normalization, and available tools is followed by a more in-depth treatment of differential gene expression detection, clustering techniques, pathway extraction, network model building, biomarker evaluation, and model identification. Both clinical and research data will be considered. The student will develop skills in statistical analysis and data mining, including statistical detection theory, nonlinear and multiple regression, entropy measurement, detection of hidden patterns in data, heuristic search, and learning algorithms. Applied mathematical concepts and biological principles will be introduced, and students will focus on algorithm design and software application for designing and implementing novel ways of analyzing gene, protein, and metabolic expression data. Students will complete data analysis assignments individually and in small teams.

Prerequisites

605.205 or equivalent or a prior course in bioinformatics, a course in probability and statistics, and ability to program in a high-level language.

Course Notes

There are no exams, but programming assignments are intensive. Students in the MS Bioinformatics program may take both this course and 410.671 Microarrays and Analysis, as the content is largely mutually exclusive.

Instructor: Boon

605.755  Systems Biology

During the last decade, systems biology has emerged as an effective tool for investigation of complex biological problems, placing emphasis on the analysis of large-scale data sets and quantitative treatment of experimental results. In this course, students will explore recent advances in systems biology analysis of intracellular processes. Examples of modeling and experimental studies of metabolic, genetic, signal transduction, and cell cycle regulation networks will be studied in detail. The classes will alternate between consideration of network-driven and network element (gene, metabolite, or protein)-driven approaches. Students will learn to use Boolean, differential equations, and stochastic methods of analysis and will become acquainted with several powerful experimental techniques, including basics of microfabrication and microfluidics. For their course projects, students will develop models of a signal transduction or metabolic pathway.

Prerequisites

Courses in molecular biology (605.205 Molecular Biology for Computer Scientists or 410.602 Molecular Biology) and differential equations.

Instructor: Levenko

605.759  Independent Project in Bioinformatics

This course is for students who would like to carry out a significant project in bioinformatics as part of their graduate program. The course may be used to conduct minor research, an in-depth literature survey, or a software implementation related to recent developments in the field. Students who enroll in this course are encouraged to attend at least one industry conference in bioinformatics that is related to their area of study. To enroll in this course, the student must be within two courses of degree completion and must obtain the approval and support of a sponsoring faculty member.

Course Notes

A student may not receive credit for both 605.759 and 605.802 Independent Study in Computer Science II.

Instructor: Staff

605.782  Web Application Development with Java

This project-oriented course will enable the students to use various techniques for building browser-based applications for dynamically generated websites, e-commerce, web-enabled enterprise computing, and other applications that require web access to server-based resources. Particular attention will be paid to methods for making web-based applications efficient, maintainable, and flexible. The course will use at least two sets of tools: servlets/JSP and a higher-level Java-based framework such as JSF 2.0. Major topics will include handling HTTP request information, generating HTTP response data, tracking sessions, designing custom tag libraries or components, page templating, asynchronous page updates with Ajax, and separating content from presentation through use of the MVC architecture. Additional topics may include HTML5, database access techniques for web apps, web app security,
and dependency injection in web apps (e.g., with the Spring framework).

**Prerequisites**
605.481 Principles of Enterprise Web Development or equivalent Java experience.

**Course Notes**
Formerly 605.782 Web Application Development with Servlets and JavaServer Pages (JSP).

**Instructors:** Chaikin, Chittargi, Hall

Online Option Available

605.787 Rich Internet Applications with Ajax
Using a web browser to access online resources is convenient because it provides universal access from any computer on any operating system in any location. Unfortunately, it often results in a poor user experience because HTML is a weak and noninteractive display language and HTTP is a weak and inefficient protocol. Full-fledged browser-embedded programs (e.g., ActiveX components, Java applets) have not succeeded in penetrating the market adequately, so a new class of applications has grown up that uses only the capabilities already available in most browsers. These applications were first popularized by Google but have since exploded in popularity throughout the developer community. The techniques to implement them were based on a group of technologies collectively known as Ajax, and the resultant applications were richer than the relatively static pure-HTML-based web applications that preceded them. These applications have become known as Ajax applications, rich internet applications, or Web 2.0 applications. This course will examine techniques to develop and deploy Ajax applications. We will look at the underlying techniques, then explore client-side tools (e.g., scriptaculous), server-side tools (e.g., Direct Web Remoting), and hybrid tools (e.g., the Google Web Toolkit) to simplify the development process. We will also examine closely related technologies such as Flash/Flex and OpenLaszlo, along with the accompanying issues of usability, efficiency, security, and portability.

**Prerequisites**
605.782 Web Application Development with Java or equivalent servlet and JSP experience.

**Instructors:** Chaikin, Hall, Shyamsunder

Online Option Available

605.788 Big Data Processing Using Hadoop
Organizations today are generating massive amounts of data that are too large and too unwieldy to fit in relational databases. So, organizations and enterprises are turning to massively parallel computing solutions such as Hadoop for help. The Apache Hadoop platform, with Hadoop Distributed File System (HDFS) and MapReduce (M/R) framework at its core, allows for distributed processing of large data sets across clusters of computers using the map and reduce programming model. It is designed to scale up from a single server to thousands of machines, offering local computation and storage. The Hadoop ecosystem is sizable in nature and includes many subprojects such as Hive and Pig for big data analytics, HBase for real-time access to big data, Zookeeper for distributed transaction process management, and Oozie for workflow. This course breaks down the walls of complexity of distributed processing of big data by providing a practical approach to developing applications on top of the Hadoop platform. By completing this course, students will gain an in-depth understanding of how MapReduce and Distributed File Systems work. In addition, they will be able to author Hadoop-based MapReduce applications in Java and also leverage Hadoop subprojects to build powerful data processing applications.

**Prerequisites**
605.481 Principles of Enterprise Web Development or equivalent Java experience.

**Course Notes:** This course may be counted toward a three-course track in Databases and Knowledge Management.

**Instructors:** D. May, Shyamsunder
Chemical and Biomolecular Engineering

In the past decade, the scope of chemical and biomolecular engineering has expanded dramatically. While many chemical engineers continue to work in the chemical and petroleum industries, a growing number can also be found employed by biotechnology and pharmaceutical companies, electronics manufacturing facilities, or the environmental divisions of corporations or government institutions. In each of these industries, the chemical engineering concepts of transport phenomena, reaction kinetics, and thermodynamics are fundamental to technical issues addressed by engineers.

To recognize the growing need for chemical and biomolecular engineers to acquire a broad range of skills in the basic sciences and related engineering fields, in addition to advanced training in core chemical and biomolecular engineering competencies, Johns Hopkins has developed a flexible Master of Chemical and Biomolecular Engineering program with concentrations in two subfields: (1) Cell and Molecular Biotechnology/Biomaterials and (2) Nano-/Microtechnology and Colloids and Interfaces. Hopkins will also continue to offer the traditional Master of Chemical Engineering degree in which the student develops a core program in chemical and biomolecular engineering, augmented with elective courses from related engineering fields, the basic sciences, and mathematics. This degree encompasses a professional, non-thesis curriculum for practicing engineers.

Program Committee
Michael Betenbaugh, Program Chair
Assistant Professor, Chemical and Biomolecular Engineering
Whiting School of Engineering
Konstantinos Konstantopoulos, Department Chair
Professor, Chemical and Biomolecular Engineering
Whiting School of Engineering

Admissions Requirements
Applicants must be in the last semester of their undergraduate study or hold a bachelor’s degree in chemical engineering from an accredited college or university. They must have earned a grade point average of at least 3.0 on a 4.0 scale in upper-level undergraduate courses or hold a graduate degree in a technical discipline. Applicants with a bachelor’s degree in a related science or engineering field may be considered if they have taken a sufficient number of undergraduate chemical and biomolecular engineering courses. (See additional admission requirements for non-chemical engineering majors below.) All admission decisions are made by the program committee on a case-by-case basis.

Program Requirements
Upon entering the program, students must complete a program plan and submit it to the program chair for approval. Candidates must complete the required course work within five years of admission.

Requirements for Master of Chemical and Biomolecular Engineering
To earn the Master of Chemical and Biomolecular Engineering degree, a student must complete at least 10 one-term courses approved by the student’s advisor. Of these, at least six courses must be from the Chemical and Biomolecular Engineering Department. Students are allowed to count 400-level courses towards their MSE degree if (1) the course is not offered at the 600 level and (2) if the department offering the course considers it to be a graduate-level course. Courses offered at both the 400 and 600 level must be taken at the 600 level.

Students are strongly encouraged to take the following four courses as part of their course requirements:

- 545.602 Cellular and Molecular Biotechnology of Mammalian Systems
- 545.615 Interfacial Science with Applications to Nanoscale Systems
- 545.630 Thermodynamics and Statistical Mechanics
- 545.652 Fundamentals of Biortransport Phenomena

In addition, the remaining two to four courses can be from the EP program, and no more than two courses can be selected from the Krieger School of Arts and Sciences Advanced Academic Program in Biotechnology (courses listed under Group III). If a course is not offered in a given term, students may seek advice from the program director regarding appropriate substitutions.

Requirements for Master of CBE with a Focus Area in Cell and Molecular Biotechnology/ Biomaterials

Within the past two decades, remarkable advances have taken place in the life sciences. Chemical and biomolecular engineers will be essential for putting many of these basic science discoveries into practical use. To accomplish these goals, chemical engineers must understand biology and communicate with the life scientists. EP offers a program that provides chemical engineering students with complementary exposure to the life sciences and biomedical engineering. To earn the Master of Chemical Engineering/Cell and Molecular Biotechnology/Biomaterials, the student will work with his or her advisor to take courses that will give a solid foundation in Cell and Molecular Biotechnology/Biomaterials.

Some of the electives that will count towards the course requirements include:

- 510.607 Biomaterials II
- 510.617 Advanced Topics in Biomaterials
- 545.602 Cellular and Molecular Biotechnology of Mammalian Systems
Additionally, students may complete two to three courses selected from either the Group II offerings of the Whiting School Master of Science in Applied Biomedical Engineering program and/or Group III offerings of the Krieger School of Arts and Sciences Master of Science in Biotechnology program.

Requirements for Master of CBE with a Focus Area in Nano-/Microtechnology and Colloids and Interfaces

Nano- and microtechnology involves the science and technology of extreme miniaturization. We live in an era where it has become possible to structure materials and devices on the nanometer-length scales to allow for unprecedented control over the chemical, electronic, and optical properties of materials. Moreover, when the size of the structures and devices approaches the nanometer-length scales, quantum and atomistic properties dominate, giving rise to new and novel phenomena such as quantum conductance and unusual chemical, mechanical, and optical properties. This degree will focus on the challenges of fabricating such small structures and devices, methods to characterize the structures, fundamental properties, and applications. To earn the Master of Chemical Engineering Nano-/Microtechnology and Colloids and Interfaces, the student will work with his or her advisor to take courses that will give a solid foundation in nano-/microtechnology and colloids and interfaces.

Some of the electives that will count towards the course requirements include:

- 520.772 Advanced Integrated Circuits
- 545.604 Therapeutic and Diagnostic Colloids
- 545.615 Interfacial Science with Applications to Nanoscale Systems
- 545.640 Micro and Nanotechnology
- 545.630 Thermodynamics and Statistical Mechanics

Program Electives

Group I: Whiting School Chemical and Biomolecular Engineering Elective Courses

- 545.603 Colloids and Nanoparticles
- 545.610 Fundamentals of Membrane Science for Filtration Applications
- 545.626 Introduction to Biomacromolecules
- 545.640 Micro- and Nanotechnology

Group II: Whiting School Applied Biomedical Engineering Courses

- 580.625/626 Structure and Function of the Auditory and Vestibular Systems
- 580.632 Ionic Channels in Excitable Membranes
- 585.405/406 Physiology for Applied Biomedical Engineering
- 585.407 Molecular Biology
- 585.408 Medical Sensors and Devices
- 585.605 Medical Imaging
- 585.606 Medical Image Processing
- 585.608 Biomaterials
- 585.609 Cell Mechanics
- 585.610 Biochemical Sensors
- 585.618 Biological Fluid and Solid Mechanics

Group III: Krieger School Biotechnology Core Courses and Elective Courses

- 410.601 Advanced Biochemistry
- 410.602 Molecular Biology
- 410.603 Advanced Cell Biology I
- 410.645 Biostatistics

Additional Admission Requirements for Non-Chemical Engineering Majors

To be considered for the Master of Chemical Engineering Program, undergraduates with a bachelor’s degree in a science or other engineering discipline must have a background in mathematics through differential and integral calculus and differential equations and have completed undergraduate course work in physical chemistry and thermodynamics. In addition, the applicants must complete the following undergraduate chemical engineering courses from the day program of the Whiting School of Engineering or other peer institution:

Group IV: Whiting School of Engineering Non-Chemical Engineering Majors Prerequisite Courses

In some cases, undergraduate courses from other engineering or science disciplines may be substituted for these chemical engineering courses when there is significant overlap in course material. For those applicants who can demonstrate significant undergraduate preparation in a particular area, the related undergraduate course requirement may be waived. Permission to substitute other undergraduate courses or waive course requirements will be at the discretion of the program chair.

- 545.203 Engineering Thermodynamics
- 545.204 Applied Physical Chemistry
- 545.301 Kinetic Processes
- 545.303 Transport Phenomena I
- 545.304 Transport Phenomena II
Course Descriptions

545.202  Introduction to Chemical Engineering
         Process Analysis
This course provides an introduction to chemical engineering
and the fundamental principles of chemical process analysis,
including formulation and solution of material and energy
balances on chemical processes. Reductionist approaches to
the solution of complex, multiunit processes will be empha-
sized, along with an introduction to the basic concepts of
thermodynamics and chemical reactions.

Prerequisites
030.101 Introductory Chemistry, 171.101 General Physics
for Physical Science Majors I.

Course Notes
Not for graduate credit.

Instructors: Dahuron, Prakash

545.203  Engineering Thermodynamics
This course covers the formulation and solution of mate-
rial, energy, and entropy balances, with an emphasis on open
systems. A systematic problem-solving approach is developed
for chemical process-related systems. This approach consists
of decoupling the process into its components, establishing
relationships between the known and unknown variables,
assembling the information needed to solve for the unknown
variables, and then obtaining a physically meaningful solu-
tion. Extensive use is made of classical thermodynamic rela-
tionships and constitutive equations. Applications include
the analysis and design of engines, refrigerators, heat pumps,
compressors, and turbines.

Prerequisites
030.101 Introductory Chemistry, 171.101 General Physics
for Physical Science Majors I, and either 540.202 or permis-
sion of instructor.

Co-requisite: 110.202 Calculus III (Calculus of Several
Variables).

Course Notes
Not for graduate credit.

Instructor: Frechette

545.204  Applied Physical Chemistry
This course offers an introduction to the methods used to
solve phase and chemical equilibria problems. The basic ther-
modynamic relationships to describe phase equilibrium of
single-component and multicomponent systems are devel-
oped. Thermodynamic models for calculating fugacity are
also developed and the thermodynamic models for calculating
fugacity are applied to their solution.

Prerequisites
540.203 Engineering Thermodynamics and either 540.202 or
permission of instructor.

Course Notes
Not for graduate credit.

Instructors: Konstantopoulos, Prakash

545.301  Kinetic Processes
This course provides a review of numerical methods in reactor
design, including homogeneous kinetics, and interpretation
of reaction rate data; batch, plug flow, and stirred tank reactor
analyses, including CSTRs in series; selectivity and optimiza-
tion considerations in multiple reaction systems; nonisother-
mal reactors; elements of heterogeneous kinetics, including
adsorption isotherms and basic Hougen-Watson rate mod-
els; coupled transport and chemical reaction rates; and fixed
bed reactor design, including axial dispersion models. A brief
introduction to residence time distributions and non-ideal
reactor models is also provided.

Prerequisites
540.203 Engineering Thermodynamics and 540.303 Trans-
port Phenomena I, and either 540.202 or permission of
instructor.

Course Notes
Not for graduate credit.

Instructors: Cui, Goffin

545.303  Transport Phenomena I
This course provides an introduction to the field of transport
phenomena, including molecular mechanisms of momentum
transport (viscous flow); energy transport (heat conduction);
mass transport (diffusion); isothermal equations of change
(continuity, motion, and energy); the development of the
Navier Stokes equation; the development of nonisothermal
and multicomponent equations of change for heat and mass
transfer; and exact solutions to steady-state, isothermal uni-
directional flow problems and to steady-state heat and mass
transfer problems. The analogies between heat, mass, and
momentum transfer are emphasized throughout the course.

Prerequisites
A grade of C or better in Calculus I, II, and III and 540.202
or permission of instructor.

Course Notes
Not for graduate credit.

Instructors: Konstantopoulos, Prakash
545.304 Transport Phenomena II
Topics covered in this course include dimensional analysis and dimensionless groups, laminar boundary layers, introduction to turbulent flow, definition of the friction factor, macroscopic mass, momentum and mechanical energy balances (Bernoulli’s equation), metering of fluids, convective heat and mass transfer, heat and mass transfer in boundary layers, correlations for convective heat and mass transfer, boiling and condensation, and interphase mass transfer.

Prerequisites
540.303 Transport Phenomena I and either 540.202 or permission of instructor.

Course Notes
Not for graduate credit.

Instructor: Drazer

545.305 Modeling and Statistical Analysis of Data for Chemical and Biomolecular Engineers
Collecting and analyzing data is an indispensable component of any scientific enterprise. The sequence of operations that is typical in science is as follows: hypothesis to data to inference. Because data are almost always imperfect (or incomplete), we have to rely on probability theory to infer the validity of the hypothesis. In this course, we adopt the Laplace-Bayes approach to probability theory and suggest how we can use this approach to reason in situations of imperfect data. Concepts such as determining the odds ratio and the role of Occam’s factor, etc., will be discussed. We will motivate commonly encountered probability distributions using examples in chemical engineering. Modeling is an indispensable component of data analysis, and we will rely on MATLAB and Python programming environments to become familiar with computational aspects of data analysis.

Prerequisites

Course Notes
Not for graduate credit.

Instructor: Asthagiri

545.306 Chemical and Biological Separations
This course covers principles of staged and continuous-contacting separation processes. Examples include adsorption, distillation, extraction, and process synthesis.

Prerequisites
540.202 Introduction to Chemical Engineering Process Analysis and 540.303 Transport Phenomena I

Course Notes
Not for graduate credit

Instructor: Betenbaugh

545.311 Chemical Engineering Laboratory
Students learn to characterize equipment whose operation is not well defined by identifying the important operating variables, deciding how best to obtain them, and using measured or calculated values of these operating variables to predict and improve performance. Each student analyzes four of the following experiments: distillation, gas absorption, liquid-liquid extraction, chemical kinetics in a tubular flow reactor, and fermentation. In addition to having technical objectives, this course stresses oral and written communication skills and the ability to work effectively in groups.

Prerequisites

Course Notes
Not for graduate credit.

Instructors: Dahuron, Gerecht, Goffin, Ostermeier

545.314 Chemical Engineering Process Design
This course provides an introduction to design methods for multiunit processes, including flowsheet development through reaction and separation-path synthesis; degree of freedom analysis for large systems; equipment design and specification; and estimation of capital costs, operating costs, and cash flow. Other topics include optimization techniques and energy integration. Simulation packages, such as ChemCAD, are also introduced. Written reports and oral presentations are required on assigned design projects.

Prerequisites
540.301, 540.304, 540.306, and either 540.202 or permission of instructor.

Course Notes
Not for graduate credit.

Instructors: Dahuron, Goffin

545.420 Build a Genome
In this combination lecture/laboratory “Synthetic Biology” course, students will learn how to make DNA building blocks used in an international project to build the world’s first synthetic eukaryotic genome, Saccharomyces cerevisiae v. 2.0. Please study the wiki syntheticyeast.org for more details about the project. After participating in a biotechnology boot-camp, students will have 24/7 access to computational and wet-lab resources and will be expected to spend 15–20 hours per week on this course. Advanced students will be expected to contribute to the computational and biotech infrastructure.

Prerequisites
Permission of instructors. Interview required. Must understand the fundamentals of DNA structure, DNA electrophoresis and analysis, and polymerase chain reaction (PCR) and must be either experienced with molecular biology lab work or adept at programming with a biological twist. Co-listed with 020.420, 020.451, and 580.420.

Instructor: Ostermeier
545.426  Introduction to Biomacromolecules
This course introduces modern concepts of polymer physics to describe the conformation and dynamics of biological macromolecules such as filamentous proteins and nucleic acids. We will introduce scattering techniques and micromanipulation techniques, as well as rheology, applied to the study of polymers.

Instructor: Wirtz

545.437  Application of Molecular Evolution to Biotechnology
One of the most promising strategies for successfully designing complex biomolecular functions is to exploit nature’s principles of evolution. This course provides an overview of the basics of molecular evolution as well as its experimental application to the engineering of proteins, DNA, and RNA with functions of therapeutic, scientific, or economic value. The course will cover the generation of diversity (e.g., mutagenesis and DNA shuffling), the coupling of genotype and phenotype (e.g., surface display of proteins and peptides), and methods for screening and selection.

Prerequisites
Junior standing and a basic understanding of recombinant DNA technology.

Instructor: Ostermeier

545.440  Micro- and Nanotechnology
Micro-/nanotechnology is the field of fabrication, characterization, and manipulation of extremely small objects (dimensions on the micron- to nanometer-length scale). Microscale objects, because of their small size, are expected to be at the frontier of technological innovation for the next decade. This course will include a description of the materials used in microtechnology, methods employed to fabricate nanoscale objects, techniques involved in characterizing and exploiting the properties of small structures, and examples of how this technology is revolutionizing the areas of electronics and medicine.

Course Notes
This course is cross-listed with 540.640.

Instructor: Gracias

545.447  System Safety and Risk Management
Methods, mathematics, and management approaches for evaluating the safety of complex technical systems are presented. Examples of risk assessments pertaining to the design, operation, siting, transportation, and emergency planning of both chemical and nuclear materials are studied. Topics include probability and reliability concepts, failure data analysis, FMEA (Failure Modes and Effects Analysis), fault-tree and event-tree techniques, human factors and human error models, multi-objective risk assessment, optimization and display of information, safety goals, ethics, perceptual risk, reliability assurance and maintenance, cost-benefit and analysis for safety improvements, accident mitigation, and research priority setting. Also, radiological and toxicological aspects of consequence and modeling for estimating environmental and public health impacts are reviewed.

Instructor: Staff

545.449  Statistical Design of Experiments
This course introduces the basic concepts that underlie modern statistically designed experimental programs. These programs typically test many variables simultaneously and are very efficient tools for developing empirical mathematical models, which accurately describe physical and chemical processes. They are readily applied to production plant, pilot plant, and laboratory systems and should be a part of every practicing engineer’s repertoire. Topics covered include fundamental statistics; the statistical basis for recognizing real effects in noisy data; statistical tests and reference distributions; analysis of variance; construction, application, and analysis of factorial and fractional factorial designs; screening design; response surface and optimization methods; and application to plant operations.

Instructor: Staff

545.475  Spectroscopic and Analytical Methods
This is an advanced course in characterization of macromolecules using optical, thermal, and mass spectrometric techniques. Microscopy and surface analysis methods will also be explored. The use of each method will be discussed in terms of the design, construction, and operation of the instrumentation. This will be followed by application of the method to problems in macromolecular characterization.

Instructor: Staff

545.602  Cellular and Molecular Biotechnology of Mammalian Systems
This course covers molecular biology techniques, including DNA, RNA, and proteins; control of gene expression; microarray technology and proteomics; cell-cell signaling and communication; cell adhesion; extracellular matrix; introductory glycobiology; cell structure, including membrane, cytoskeleton, organelles, proteins secretion and degradation; cell replication and death, including cell cycle, cell division, senescence, and apoptosis; multicellular systems, including fertilization; tissue development, including nervous system, ectoderm (neuronal crest), mesoderm, endoderm metamorphosis, regeneration, and aging; and stem cell biology, including adult and fetal stem cells, germ and embryonic stem cells, cell expansion of undifferentiated and progenitor cells, differentiation regulation, and control/engineering of stem cell renewal and differentiation in vitro.

Instructors: Betenbaugh, Konstantopoulos

545.603  Colloids and Nanoparticles
This course explains the fundamental principles related to interactions, dynamics, and structure in colloidal, nanoparticle, and interfacial systems. Concepts covered include
hydrodynamics, Brownian motion, diffusion, sedimentation, electrophoresis, colloidal and surface forces, polymeric forces, aggregation, deposition, and experimental methods. Modern topics related to colloids in nanoscience and technology will be discussed throughout the course, with frequent references to recent literature.

**Instructor:** Bevan

**545.604 Therapeutic and Diagnostic Colloids**

The inefficient or inappropriate transport of particles in complex biological fluids in the body currently limits the effectiveness of nanoparticle-based strategies aimed at providing a variety of breakthroughs in medicine, including drug delivery systems to improved particles for advanced imaging and diagnostics. Many bodily fluids serve as barriers to particle transport to desired locations, and some are microporous, highly viscous, and/or elastic in nature. This course seeks to provide a fundamental understanding of the phenomena, including fluid micro-, meso-, and macrorheology, that governs nano- and microparticle transport in important biological fluids, including the blood, airways, mucus, and living cells. A comparison of macroscopic and microscopic particle transport behavior, including comparisons of ensemble-average transport behavior and individual particle behavior, is a common thread that runs throughout the course. The importance of particle physicochemical properties in achieving desired particle transport through biological barriers to desired sites of action will be addressed. The course will include a case study involving the design criteria of efficient synthetic systems for gene delivery in the lung airways.

**Instructor:** Wirtz

**545.610 Fundamentals of Membrane Science for Filtration Applications**

This course focuses on the principles underlying the formation of micro- to nanostructured membranes applied in a range of modern filtration technologies, such as microfiltration, ultrafiltration, nanofiltration, reverse osmosis, pervaporation, gas separation, electrodialysis, hemodialysis, fuel cells, drug delivery, tissue engineering, and sensors. Polymeric membranes prepared by phase separation will be examined in detail, while interfacial polymerization and sol-gel processing to prepare thin film composites and ceramic membranes, respectively, will also be studied. The first part of the course will discuss how concepts from thermodynamics, multicomponent diffusion, and fluid/solid mechanics are applied to membrane formation theory. The second part of the course will present membrane transport theory and demonstrate how engineering principles are applied to the various filtration applications and the design of modules.

**Prerequisites**

Graduate Thermodynamics and Transport Phenomena are recommended. Programming experience (MATLAB/ Mathematica).

**Instructor:** Prakash

**545.612 Interfacial Phenomena in Nanostructure Materials**

All properties of materials change when encountered or fabricated with nanoscale structure. In this class, we will examine how the properties of nanostructured materials differ from their macroscopic behavior, primarily due to the presence of large interfacial areas relative to the volume scale. General topics include the structure of nanostructured materials (characterization and microscopy), thermodynamics (effects of high curvatures and surface elasticity), kinetics and phase transformations (diffusion and morphological stability), and electronic properties (quantum confinement and effects of dimensionality).

**Course Notes**

This is a course of the Whiting School’s Department of Chemical and Biomolecular Engineering.

**Instructor:** Staff

**545.614 Computational Protein Structure Prediction and Design**

The prediction of protein structure from the amino acid sequence has been a grand challenge for more than 50 years. With recent progress in research, it is now possible to blindly predict many protein structures and even to design new structures from scratch. This class will introduce the fundamental concepts in protein structure, biophysics, optimization, and informatics that have enabled the breakthroughs in computational structure prediction and design. Problems covered will include protein folding and docking, design of ligand-binding sites, design of turns and folds, and design of protein interfaces. Classes will consist of lectures and hands-on computer workshops. Students will learn to use molecular visualization tools and write programs with the PyRosetta protein structure software suite, including a computational project.

**Prerequisites**

Programming experience is helpful but not required.

**Instructor:** Gray

**545.615 Interfacial Science with Applications to Nanoscale Systems**

Nanostructured materials intrinsically possess large surface area (interface area) to volume ratios. It is this large interfacial area that gives rise to many of the amazing properties and technologies associated with nanotechnology. In this class, we will examine how the properties of surfaces, interfaces, and nanoscale features differ from their macroscopic behavior. We will compare and contrast fluid-fluid interfaces with solid-fluid and solid-solid interfaces, discussing fundamental interfacial physics and chemistry, as well as touching on state-of-the-art technologies.

**Instructor:** Frechette

**545.626 Introduction to Biomacromolecules**

This course introduces modern concepts of polymer physics to describe the conformation and dynamics of biological macro-
molecules such as filamentous actin, microtubule, and nucleic acids. We will introduce scattering techniques and micromanipulation techniques, as well as theory applied to the study of polymers for tissue engineering and drug delivery applications.

**Instructor:** Wirtz

**545.630 Thermodynamics and Statistical Mechanics**

We will develop equilibrium thermodynamics and statistical mechanics from the unified perspective of entropy maximization subject to constraints. After briefly reviewing classical thermodynamics, we will undertake the study of statistical mechanics leading up to the study of liquids, especially liquid water, and of the hydration of (bio)molecules. We will show how hydration of solutes is conceptually simple when viewed on the basis of quasi-chemical generalizations of the potential distribution theorem. We will highlight how the quasi-chemical generalizations readily allow one to include quantum chemical-level of description in the statistical mechanics of biologically interesting processes. If time permits, we will also touch on modern developments in statistical mechanics that connect non-equilibrium work to equilibrium free energies.

**Instructor:** Asthagiri

**545.637 Molecular Evolution of Biotechnology**

One of the most promising strategies for successfully designing complex biomolecular functions is to exploit nature’s principles of evolution. This course provides an overview of the basics of molecular evolution as well as its experimental implementation. Current research problems in evolution-based biomolecular engineering will be used to illustrate principles in the design of biomolecules (i.e., protein engineering, RNA/DNA engineering), genetic circuits, and complex biological systems including cells.

**Instructor:** Ostermeier

**545.640 Micro- and Nanotechnology**

Micro-/nanotechnology is the field of fabrication, characterization, and manipulation of extremely small objects (dimensions on the micron- to nanometer-length scale). Microscale objects, because of their small size, are expected to be at the frontier of technological innovation for the next decade. This course will include a description of the materials used in microtechnology, methods employed to fabricate nanoscale objects, techniques involved in characterizing and exploiting the properties of small structures, and examples of how this technology is revolutionizing the areas of electronics and medicine.

**Course Notes**

This course is cross-listed with 540.440.

**Instructor:** Gracias

**545.642 Advanced Chemical Kinetics and Reactor Design**

This course covers complex reaction networks, Wei-Prater analysis, and the Himmelblau-Jones-Bischoff method. Detailed coverage is provided of Hougen-Watson models for heterogeneous catalytic reaction kinetics, model discrimination, and parameter estimation. Other topics include coupled heterogeneous reaction and transport; generalized moduli catalyst deactivation models; batch reactors, CSTRs, and PFRs; fixed bed reactors including stability criteria and multibed optimization; residence time distributions and non-ideal reactor models; and fluidized bed and multiphase reactors.

**Instructor:** Staff

**545.652 Fundamentals of Biotransport Phenomena**

This lecture course introduces students to the application of engineering fundamentals from transport and kinetic processes to vascular biology and medicine. The first half of the course addresses the derivation of the governing equations for Newtonian fluids and their solution in the creeping flow limit. The second half of the course considers how these concepts can be used to understand the behavior of a deformable cell near planar surfaces.

**Prerequisites**

Undergraduate Transport Phenomena preferred.

**Instructor:** Staff
Civil Engineering

The civil engineering profession is dedicated to developing and applying scientific and technological knowledge to serve the needs of our society. Buildings, power plants, roadways, bridges, water supply systems, wastewater systems, and ocean and estuarine structures are all part of the infrastructure of society that comes under the purview of the civil engineering discipline. Increasingly, civil engineers are also involved in the development of less traditional structures and systems, such as mechanical prostheses and space vehicles. In addition, the scope of expertise of the modern civil engineer must include a concern for environmental, social, and economic issues. To better prepare our civil engineering workforce to meet the challenges they will face, Johns Hopkins' Master of Civil Engineering (MCE) program offers a wide variety of graduate courses in the areas of structural engineering, geotechnical engineering, and coastal engineering.

Program Committee
Rachel H. Sangree, Program Chair
Lecturer, Civil Engineering
Whiting School of Engineering

Lucas de Melo
Senior Engineer, Geosyntec Consultants
Adjunct Professor, Civil Engineering
Whiting School of Engineering

John Matteo
Associate, Robert Silman Associates
Lecturer, Civil Engineering
Whiting School of Engineering

Benjamin W. Schafer
Department Chair, Civil Engineering
Whiting School of Engineering

Admission Requirements
Applicants must meet the general requirements for admission to graduate study outlined in Admission Requirements (page 4). Each applicant must have a degree in civil engineering or an appropriate related field, which provides the necessary preparation for graduate-level courses. All admissions decisions are made by the program committee on an individual basis.

Course Requirements
The Master of Civil Engineering program allows students to develop a program that suits their professional needs. Students may choose to focus their studies in Structural Engineering or Geotechnical Engineering by selecting courses from one of those two established focus areas. Alternatively, students who do not identify with either of those two disciplines may work with their advisors to select a broad yet cohesive group of courses to make up a general program of study.

I. Required Mathematics Course
All students in the MCE program must complete one of the following Applied Mathematics courses:
535.441 Mathematical Methods for Engineers
615.441 Mathematical Methods for Physics and Engineering

II. Program Focus Areas
Students who choose to focus their studies in Structural Engineering or Geotechnical Engineering should select two core courses and a minimum of four electives from the lists below. Required core courses in each focus area are denoted by an asterisk (*). See Course Requirements for more information.

Structural Engineering Focus Area
565.430 Structural Design with Timber and Masonry
565.605 Advanced Reinforced Concrete Design
565.620 Advanced Steel Design
565.630 Prestressed Concrete Design
565.640 Instrumentation in Structural and Geotechnical Engineering
565.650 Port and Harbor Engineering
565.670 Coastal Structures
565.729 Structural Mechanics*
565.730 Finite Element Methods*
565.756 Earthquake Engineering I
565.758 Wind Engineering
565.766 Earthquake Engineering II
565.784 Bridge Design and Evaluation
Course Descriptions

565.410 In Situ and Laboratory Testing Methods for Soil Construction
The course covers selection of field and laboratory testing of soils based on site conditions, project specificities, and expected soil response to project loads. In situ field testing includes standard penetration test, cone penetrometer test, pressuremeter, dilatometer, and vane shear. Laboratory tests of soil include soil characterization, direct shear, triaxial compression (static and cyclic), consolidation, and advanced testing. The course covers development of a geotechnical investigation plan, including field exploration and laboratory testing to support the design and analysis of soil constructions. In situ geotechnical monitoring instrumentation, data acquisition, and management are covered.

Prerequisites
560.305 Soil Mechanics or equivalent.

Instructor: de Melo

565.430 Structural Design with Timber and Masonry
This course offers a review of the current requirements and techniques for the design of modern structures using materials such as engineered brick and concrete masonry, timber, aluminum, and plastics. Relevant design specifications and criteria are also included.

Instructor: Sangree

565.475 Advanced Soil Mechanics
This course discusses the difference between soils and other materials; stresses in soils due to structural foundations; elastic, consolidation, and secondary consolidation settlements of footings; shear strength and stress-strain behavior of clays and sands; approximate nonlinear elastic, Mohr-Coulomb, Ramberg-Osgood, and Hyperbolic stress-strain models for soils; nonlinear Winkler foundation analysis of piles, pile groups, and drilled shafts due to vertical and horizontal loads; and foundation spring constraints for superstructure analysis.

Prerequisites
560.305 Soil Mechanics or equivalent.
formed steel shapes and overall concepts of the structural system.

**Prerequisites**
560.320 Steel Structures or equivalent.

**Instructor:** Malushte

**565.625 Advanced Foundation Design**
This course covers performance requirements and review of soil mechanics; laboratory testing, subsurface investigation, and in situ testing; bearing capacity and settlements of shallow foundations; design of spread footings and mat foundations; axial capacity of deep foundations; settlements of deep foundations; lateral capacity of deep foundations; weak, compressible, and expansible soils; earth pressure theories; and cantilever and sheet-pile retaining structures.

**Prerequisites**
560.320 Steel Structures or equivalent.

**Instructor:** Malushte

**565.630 Prestressed Concrete Design**
Topics include prestressed concrete materials, prestressing systems, and loss of prestress; analysis and design of section for flexure, shear, torsion, and compression; and consideration of partial prestress, composite sections, and slabs.

**Prerequisites**
560.325 Concrete Structures or equivalent.

**Instructor:** Hayek

**565.635 Ground Improvement Methods**
This course addresses the selection, cost, design, construction, and monitoring of ground improvement methods for problematic soils and rock. Ground improvement methods covered include wick drains, micropiles, lightweight fill materials, soil nailing, mechanically stabilized slopes and walls, grouting, stone columns, dynamic compaction, and soil mixing.

**Prerequisites**
560.320 Steel Structures or equivalent.

**Instructor:** Malushte

**565.640 Instrumentation in Structural and Geotechnical Engineering**
This course introduces concepts, technologies, procedures, and applications of instrumentation in structural and geotechnical engineering. The structural applications include bridge load rating, fatigue evaluation, connection/bearing performance, and problem diagnosis. The geotechnical applications include in situ determination of soil and rock properties and performance monitoring of soil and foundation elements. Geotechnical instrumentation details will include design phase, construction phase, and post-construction phase applications.

**Instructors:** Kesavan, Zhou

**565.645 Marine Geotechnical Engineering**
This course introduces students to soil mechanics in the marine environment. Topics covered include the nature of marine sediments, soil behavior due to cyclic loading, marine geotechnical investigations, shallow foundations and deadweight anchors, pile foundations and anchors, penetration and breakout of objects on the seafloor, marine slope stability, soft ground improvement, marine dredging, and project planning.

**Prerequisites**
560.320 Steel Structures or equivalent.

**Instructor:** Malushte

**565.650 Port and Harbor Engineering**
Planning and engineering of ports and harbors has received renewed worldwide interest as the newest super-large cargo ships push the envelope for channel depth and berthing space. This course covers planning of marine terminals and small-craft harbors, ship berthing and maneuvering considerations, port navigation, marine structures, inland navigation, marine construction planning, sediment management, and port economics. A field trip to the Port of Baltimore provides practical application of course material and shows students firsthand the unique challenges of engineering on the waterfront.

**Instructor:** Hudson

**565.660 Ocean Engineering Mechanics**
The theories governing water wave motion, from linear to nonlinear waves, are presented. Wave propagation and transformation, including shoaling, refraction, and diffraction, are shown. Wave breaking and the basic interaction of waves with structures and the ocean bottom are covered.

**Instructor:** Mouring

**565.670 Coastal Structures**
This course covers the practical design and analysis of seawalls, breakwaters, groins, and jetties. Topics include wave forces, sediment transport, and coastal zone planning.

**Instructor:** Hudson

**565.671 Sustainable Coastal Engineering**
This course emphasizes methods for adapting to coastal hazards such as hurricanes, tsunamis, and sea level rise. Topics include surf zone and nearshore processes, equilibrium beaches, beach nourishment, living shorelines and sills, bioengineering approaches, use of vegetation and vegetated buffers, and use of sand dunes and berms. Other topics include FEMA provisions for sustainable residential and building construction, hurricane-resistant construction, and flood-proofing.

**Instructor:** Mouring

**565.675 Hydrodynamics of Estuaries**
Topics that apply to estuaries include tides, shallow water waves, dispersion, sedimentation, salinity stratification and...
mixing, pollution, and flushing, with a particular emphasis on the dynamics of the Chesapeake Bay.

**Prerequisites**
575.401 Fluid Mechanics or equivalent.

**Instructor:** Staff

**565.715 Application of Numerical Methods in Geotechnical Engineering**
This course presents a review of different numerical methods and their applicability and limitations to analysis and design in geotechnical engineering. The course includes an overview of finite differences, boundary elements, and the finite element method (FEM) for stress-strain analysis of soil constructions and limit equilibrium methods for slope stability analysis. Also included are applications of FEM and slope stability software to analysis and design in geotechnical engineering.

**Instructor:** de Melo

**565.729 Structural Mechanics**
This course presents basic solid mechanics for structural engineers, including stress, strain, and constitutive laws; linear elasticity and visco-elasticity; introduction to nonlinear mechanics; static, dynamic, and thermal stresses; specialization of theory to one- and two-dimensional cases; plane stress and plane strain, rods, and beams; work and energy principles; and variational formulations.

**Course Notes**
This course is a requirement for the Structural Engineering focus area.

**Instructor:** Staff

**565.730 Finite Element Methods**
The basic concepts of the finite element method (FEM) are presented for one-, two-, and three-dimensional boundary value problems (BVPs). Problems from heat conduction and solid mechanics are addressed. The key topics include relationships among strong, weak, and variational statements of BVPs; weighted residual methods with an emphasis on the Galerkin method; specialization of Galerkin approximations of weak statements and Ritz approximations of variational statements to obtain finite element formulations; specific element formulations; convergence properties; solutions of linear systems of equations; and time-dependent problems.

**Prerequisites**
This course is a requirement for the Structural Engineering focus area.

**Instructor:** Staff

**565.742 Soil Dynamics and Geotechnical Earthquake Engineering**
This course provides a study of soil behavior under dynamic loading conditions, including wave propagation and attenuation, field and laboratory techniques for determining dynamic soil properties and cyclic strength, cyclic stress strain behavior of soils, liquefaction and evaluation of liquefaction susceptibility, nondestructive evaluation of foundation systems, and foundation design for vibratory loadings.

**Prerequisites**
560.305 or equivalent.

**Instructor:** Staff

**565.745 Retaining Structures and Slope Stability**
Topics for this course include earth pressure theories; design and behavior of rigid, flexible, braced, tied-back, slurry, and reinforced soil structures; stability of excavation, cut, and natural slopes; methods of slope stability analysis; effects of water forces; shear strength selection for analysis; and stability and seepage in embankment dams.

**Prerequisites**
560.305 or equivalent.

**Instructor:** Chen

**565.752 Structural Dynamics**
This course provides a brief review of rigid-body dynamics, Lagrange’s equations and Hamilton’s principle, free and deterministic forced vibration of undamped and damped single- and multi-degree of freedom systems, vibration of continuous systems, approximate methods of analysis, and introduction to random vibration of linear systems.

**Instructor:** Yeo

**565.756 Earthquake Engineering I**
Topics for this course include plate tectonics, seismicity of the earth, and engineering seismology—including quantification and classification of earthquake ground motions, dynamics of structures subjected to earthquake loads, design spectra, building code provisions, design concepts and detailing, soil-structure interaction, and response of special structures.

**Instructor:** Malushte

**565.758 Wind Engineering**
This course covers atmospheric circulation, atmospheric boundary layer winds, bluff-body aerodynamics, modeling of wind-induced loads, introduction to random vibration theory, response of structures to fluctuating wind loads, aeroelastic phenomena, wind-tunnel and full-scale testing, non-synoptic winds (hurricanes, tornadoes, etc.), and wind-load standards and design applications.

**Instructor:** Yeo

**565.766 Earthquake Engineering II**
This course teaches the principles of seismic resistant design in terms of importance of ductile behavior of materials, members, and structural systems (with emphasis on the seismic “fuse” concept). Seismic design practice for steel and concrete structures per the current U.S. codes will be covered for structural systems that include steel moment frames, steel braced
frames, concrete moment frames, concrete shear wall systems, buckling restrained braced frames, and others.

**Prerequisites**

565.756 Earthquake Engineering I

**Instructor:** Malushe

**565.784 Bridge Design and Evaluation**

This graduate-level course covers primary subjects and fundamental principles for the design of new bridges and the evaluation of existing bridges in accordance with current AASHTO specifications. The general procedures of bridge design and bridge evaluation, respectively, will be discussed, and the corresponding AASHTO code requirements will be explained through examples. In addition, modern technologies for condition assessment and monitoring of existing bridges will be introduced. No textbook will be required. Necessary course materials will be provided through handouts.

**Instructor:** Zhou

**565.800 Independent Study in Civil Engineering**

Permission of instructor required.

**Instructor:** Staff

**565.801 Independent Study in Civil Engineering**

Permission of instructor required.

**Instructor:** Staff
Computer Science

The proliferation of computers and the expanding scope of information technology have affected virtually every aspect of human society. As a discipline, computer science is concerned with the theory, analysis, design, and implementation of processes that describe and transform information. With roots in mathematics and engineering, computer science uses formal techniques and methodologies of abstraction to create models that can be automated to solve real-world problems.

The Master of Science in Computer Science program is designed to appeal to a broad range of individuals. The program balances theory with practice, offers an extensive set of traditional and state-of-the-art courses, and provides the necessary flexibility to accommodate students with various backgrounds. As a result, the program will appeal to computer professionals with undergraduate degrees in computer science seeking to broaden or deepen their understanding of the discipline, as well as to scientists and engineers who wish to gain deeper insights into the field of computing.

Courses are offered across a wide variety of topic areas including distributed computing, software engineering, cybersecurity, data communications and networking, bioinformatics, database systems, artificial intelligence, human-computer interaction, systems, and theory. Research and development interests of the faculty span the entire spectrum of computer science.

Students may take courses at the Applied Physics Laboratory, the Montgomery County Campus, the Dorsey Center, and online. Extensive computing facilities are available and can be reached from any of the sites or from home. A variety of software systems, applications, development tools, and specialized lab facilities are also supported.

Program Committee

Thomas A. Longstaff, Program Chair
Principal Professional Staff
Applied Physics Laboratory

J. Miller Whisnant, Interim Program Vice Chair
Principal Professional Staff
Applied Physics Laboratory

Robert S. Grossman, Program Vice Chair Emeritus
Principal Professional Staff (ret.)
Applied Physics Laboratory

Eleanor Boyle Chlan, Associate Program Chair
Senior Lecturer in Computer Science
Whiting School of Engineering

John A. Piorkowski
Principal Professional Staff
Applied Physics Laboratory

Michael Smeltzer
Senior Professional Staff
Applied Physics Laboratory

Admission Requirements

Applicants must have received a grade of A or B in each of the prerequisite undergraduate computer science courses. Applicants must meet the general requirements for admission to a graduate program, as stated in Admission Requirements (page 4). In addition, computer science master’s degree candidates must have taken one year of calculus, a course in programming using a modern programming language such as Java or C++, a course in data structures, a course in computer organization, and a mathematics course beyond calculus (e.g., discrete mathematics, linear algebra, or differential equations). This is summarized below:

Computer Science Courses:
A. Introduction to Programming Using Java or C++—one term
B. Data Structures—one term
C. Computer Organization—one term

Mathematics Courses:
A. One year of calculus—two semesters or three quarters
B. Additional mathematics course beyond calculus—one term

Applicants who have not taken the prerequisite undergraduate courses may satisfy admission requirements by completing the specified courses with grades of A or B. The program offers the following undergraduate courses, which may be taken as needed to satisfy the computer science prerequisites and the requirement for a mathematics course beyond calculus:

- 605.201 Introduction to Programming Using Java
- 605.202 Data Structures
- 605.203 Discrete Mathematics
- 605.204 Computer Organization

Advanced Certificate for Post-Master’s Study in Computer Science

Applicants who have already completed a master’s degree in computer science or a related discipline are eligible to apply for an Advanced Certificate of Post-Master’s Study in Computer Science. Six one-term courses must be completed, with grades of A or B, within three years. At least five of the six courses must be Computer Science courses, and at least two of the Computer Science courses must be at the 700 level. Students are allowed to take one elective course, subject to advisor approval.

Course Requirements for Master’s Degree

Ten courses, approved by an advisor, must be completed within five years. At least eight courses must be from the Computer Science curriculum, which includes computer science courses as well as selected courses from Cybersecurity and Information Systems Engineering. Three courses must be from the same track, and at least two courses must be 700 level. No more than one course with a grade of C, and no
course with a grade lower than C, may be counted toward the degree.

While students often choose 10 courses from Computer Science, students may take up to two electives from outside Computer Science. These may be selected from Electrical and Computer Engineering, Applied and Computational Mathematics, and Applied Physics. Electives from other programs require approval of the Computer Science program chair or vice chair. Students who take electives from other programs must meet the specific course and program requirements listed for each course. In the event that the student has transfer courses accepted, they will be considered electives.

Graduate students who are not pursuing a master’s degree in computer science should consult with their advisors or with the computer science special student advisor to determine what courses must be successfully completed before 400- or 700-level computer science courses may be taken. It should be noted that 700-level courses are open only to students who have been admitted with graduate status.

Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

**Computer Science—Online**

Students may complete the Master of Science in Computer Science online, and all students may take advantage of online offerings. While not all courses are available online, a complete program is offered, and additional online courses are continually being developed. This increases the flexibility of course offerings for students wishing to pursue studies in the face-to-face format, the online format, or a combination of both.

Course content is identical to that in the face-to-face offerings but is available in a paced, asynchronous mode over the Internet. Recorded lectures with associated multimedia content are augmented with online discussions and weekly synchronous office hours. Prospective and current students should consult ep.jhu.edu for the current online course offerings, course schedules, and procedures for online programs.

**Bioinformatics**

Computer Science students may pursue a Master of Science in Computer Science with a track in bioinformatics or an Advanced Certificate for Post-Master’s Study in Bioinformatics. The advanced certificate requires that students hold a master of science in computer science or a closely related discipline, such as electrical and computer engineering or applied and computational mathematics. The certificate requires six courses, four of which must be graduate courses selected from the Computer Science Bioinformatics Concentration area. For both the track and certificate, students may take up to two electives from outside Computer Science. While these electives will typically be selected from programs in the Whiting School of Engineering, advisors can approve bioinformatics courses from other divisions of the university. Students who take electives from other programs must meet the requirements for the selected courses. Before taking any graduate computer science bioinformatics courses, students must have taken 605.205 Molecular Biology for Computer Scientists or an equivalent course and received a grade of A or B.

Students interested in a Master of Science in Bioinformatics with a focus on the interpretation of complex biological information and the analysis of sequence data using sophisticated bioinformatics software may be interested in the joint degree program offered by the Whiting School of Engineering and the Zanvyl Krieger School of Arts and Sciences. See Bioinformatics (page 45).

**Telecommunications and Networking Concentration**

The field of telecommunications and networking is one of great importance to our society. As a technical discipline, it draws from the more traditional fields of computer science and electrical engineering. Although the EP program does not offer a separate master’s degree in telecommunications and networking, students may pursue a concentration in this area as a degree candidate in Computer Science. The wide variety of courses from both Computer Science and Electrical and Computer Engineering allows students, working with advisors, to structure programs that meet their professional development needs. Seven of the 10 courses must be in the communications and networking subject area as defined by the course lists below. Students who select this concentration may take a maximum of three communications and networking courses from the Electrical and Computer Engineering courses listed below. Students are strongly encouraged to take courses from both areas. Students lacking an electrical engineering background or equivalent must take 525.202 Signals and Systems as an undergraduate prerequisite before taking Electrical and Computer Engineering telecommunications and networking courses. The Computer Science and Electrical and Computer Engineering telecommunications and networking courses for the Telecommunications and Networking Concentration are listed below.

**Foundation Courses**

All students working toward a master’s degree in computer science are required to take the following three graduate foundation courses before taking other graduate courses:

- 605.401 Foundations of Software Engineering
- 605.411 Foundations of Computer Architecture
- 605.421 Foundations of Algorithms

One or more foundation courses can be waived if a student has received an A or B in equivalent courses. In this case, the student may replace the waived foundation courses with the same number of other graduate computer science courses and may take these courses after all remaining foundation course requirements have been satisfied.

**Graduate Courses by Track**

The Computer Science tracks—including all applicable courses from Computer Science, Cybersecurity, and Information Systems Engineering—are as follows:
<table>
<thead>
<tr>
<th>Course Code</th>
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<tbody>
<tr>
<td>605.401</td>
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</tr>
<tr>
<td>605.402</td>
<td>Software Analysis and Design</td>
</tr>
<tr>
<td>605.404</td>
<td>Object Oriented Programming with C++</td>
</tr>
<tr>
<td>605.405</td>
<td>Conceptual Design for High-Performance Systems</td>
</tr>
<tr>
<td>605.407</td>
<td>Agile Software Development Methods</td>
</tr>
<tr>
<td>605.408</td>
<td>Software Project Management</td>
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<tr>
<td>605.701</td>
<td>Software Systems Engineering</td>
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<tr>
<td>605.702</td>
<td>Service-Oriented Architecture</td>
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<tr>
<td>605.704</td>
<td>Object-Oriented Analysis and Design</td>
</tr>
<tr>
<td>605.705</td>
<td>Software Safety</td>
</tr>
<tr>
<td>605.707</td>
<td>Design Patterns</td>
</tr>
<tr>
<td>605.708</td>
<td>Tools and Techniques of Software Project Management</td>
</tr>
<tr>
<td>605.709</td>
<td>Seminar in Software Engineering</td>
</tr>
<tr>
<td>605.744</td>
<td>Reverse Engineering and Vulnerability Analysis</td>
</tr>
<tr>
<td>605.411</td>
<td>Foundations of Computer Architecture</td>
</tr>
<tr>
<td>605.412</td>
<td>Operating Systems</td>
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<tr>
<td>605.414</td>
<td>System Development in the UNIX Environment</td>
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<td>605.415</td>
<td>Compiler Design</td>
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<tr>
<td>605.416</td>
<td>Multiprocessor Architecture and Programming</td>
</tr>
<tr>
<td>605.713</td>
<td>Robotics</td>
</tr>
<tr>
<td>605.715</td>
<td>Software Development for Real-Time Embedded Systems</td>
</tr>
<tr>
<td>605.716</td>
<td>Modeling and Simulation of Complex Systems</td>
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<tr>
<td>605.420</td>
<td>Algorithms for Bioinformatics</td>
</tr>
<tr>
<td>605.421</td>
<td>Foundations of Algorithms</td>
</tr>
<tr>
<td>605.422</td>
<td>Computational Signal Processing</td>
</tr>
<tr>
<td>605.423</td>
<td>Applied Combinatorics and Discrete Mathmatics</td>
</tr>
<tr>
<td>605.424</td>
<td>Logic: Systems, Semantics, and Models</td>
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<tr>
<td>605.426</td>
<td>Image Processing</td>
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<tr>
<td>605.427</td>
<td>Computational Photography</td>
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<tr>
<td>605.428</td>
<td>Applied Topology</td>
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<tr>
<td>605.429</td>
<td>Programming Languages</td>
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<tr>
<td>605.721</td>
<td>Design and Analysis of Algorithms</td>
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<tr>
<td>605.722</td>
<td>Computational Complexity</td>
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<tr>
<td>605.725</td>
<td>Queueing Theory with Applications to Computer Science</td>
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<td>605.726</td>
<td>Game Theory</td>
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<tr>
<td>605.727</td>
<td>Computational Geometry</td>
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<tr>
<td>605.728</td>
<td>Quantum Computation</td>
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<tr>
<td>605.431</td>
<td>Cloud Computing</td>
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<td>605.432</td>
<td>Graph Analytics</td>
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<td>605.448</td>
<td>Data Science</td>
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<tr>
<td>605.462</td>
<td>Data Visualization</td>
</tr>
<tr>
<td>605.741</td>
<td>Distributed Database Systems: Cloud Computing and Data Warehouses</td>
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<tr>
<td>605.744</td>
<td>Information Retrieval</td>
</tr>
<tr>
<td>605.746</td>
<td>Machine Learning</td>
</tr>
<tr>
<td>605.788</td>
<td>Big Data Processing Using Hadoop</td>
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<tr>
<td>605.441</td>
<td>Principles of Database Systems</td>
</tr>
<tr>
<td>605.443</td>
<td>The Semantic Web</td>
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<tr>
<td>605.444</td>
<td>XML Design Paradigms</td>
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<td>605.445</td>
<td>Artificial Intelligence</td>
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<td>605.446</td>
<td>Natural Language Processing</td>
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<td>605.447</td>
<td>Neural Networks</td>
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<tr>
<td>605.448</td>
<td>Data Science</td>
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<td>Information Retrieval</td>
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<tr>
<td>605.745</td>
<td>Reasoning Under Uncertainty</td>
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<tr>
<td>605.746</td>
<td>Machine Learning</td>
</tr>
<tr>
<td>605.747</td>
<td>Evolutionary Computation</td>
</tr>
<tr>
<td>605.748</td>
<td>Semantic Natural Language Processing</td>
</tr>
<tr>
<td>605.424</td>
<td>Logic: Systems, Semantics, and Models</td>
</tr>
<tr>
<td>605.788</td>
<td>Big Data Processing Using Hadoop</td>
</tr>
<tr>
<td>605.451</td>
<td>Principles of Computational Biology</td>
</tr>
<tr>
<td>605.452</td>
<td>Biological Databases and Database Tools</td>
</tr>
<tr>
<td>605.453</td>
<td>Computational Genomics</td>
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<tr>
<td>605.456</td>
<td>Computational Drug Discovery and Development</td>
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<tr>
<td>605.751</td>
<td>Computational Aspects of Molecular Structure</td>
</tr>
<tr>
<td>605.754</td>
<td>Analysis of Gene Expression and High-Content Biological Data</td>
</tr>
<tr>
<td>605.755</td>
<td>Systems Biology</td>
</tr>
<tr>
<td>605.759</td>
<td>Independent Project in Bioinformatics</td>
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<tr>
<td>605.443</td>
<td>The Semantic Web</td>
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<tr>
<td>605.716</td>
<td>Modeling and Simulation of Complex Systems</td>
</tr>
<tr>
<td>605.462</td>
<td>Data Visualization</td>
</tr>
<tr>
<td>605.467</td>
<td>Computer Graphics</td>
</tr>
<tr>
<td>605.767</td>
<td>Applied Computer Graphics</td>
</tr>
<tr>
<td>635.461</td>
<td>Principles of Human-Computer Interaction</td>
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</table>
### VIII. Data Communications and Networking

<table>
<thead>
<tr>
<th>Course Code</th>
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<tbody>
<tr>
<td>605.471</td>
<td>Principles of Data Communications Networks</td>
</tr>
<tr>
<td>605.472</td>
<td>Computer Network Architectures and Protocols</td>
</tr>
<tr>
<td>605.473</td>
<td>High-Speed Networking Technologies</td>
</tr>
<tr>
<td>605.474</td>
<td>Network Programming</td>
</tr>
<tr>
<td>605.475</td>
<td>Protocol Design and Simulation</td>
</tr>
<tr>
<td>605.477</td>
<td>Internetworking with TCP/IP I</td>
</tr>
<tr>
<td>605.478</td>
<td>Cellular Communications Systems</td>
</tr>
<tr>
<td>605.771</td>
<td>Wired and Wireless Local and Metropolitan Area Networks</td>
</tr>
<tr>
<td>605.772</td>
<td>Network Management</td>
</tr>
<tr>
<td>605.775</td>
<td>Optical Networking Technology</td>
</tr>
<tr>
<td>605.776</td>
<td>Fourth-Generation Wireless Communications: WiMAX and LTE</td>
</tr>
<tr>
<td>605.777</td>
<td>Internetworking with TCP/IP II</td>
</tr>
<tr>
<td>605.778</td>
<td>Voice Over IP</td>
</tr>
<tr>
<td>600.647</td>
<td>Advanced Topics in Wireless Networks</td>
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</tbody>
</table>

### IX. Enterprise and Web Computing

<table>
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<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>605.481</td>
<td>Principles of Enterprise Web Development</td>
</tr>
<tr>
<td>605.484</td>
<td>Agile Development with Ruby on Rails</td>
</tr>
<tr>
<td>605.486</td>
<td>Mobile Application Development for the Android Platform</td>
</tr>
<tr>
<td>605.782</td>
<td>Web Application Development with Java</td>
</tr>
<tr>
<td>605.784</td>
<td>Enterprise Computing with Java</td>
</tr>
<tr>
<td>605.785</td>
<td>Web Services with SOAP and REST: Frameworks, Processes, and Applications</td>
</tr>
<tr>
<td>605.786</td>
<td>Enterprise System Design and Implementation</td>
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<tr>
<td>605.787</td>
<td>Rich Internet Applications with Ajax</td>
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<tr>
<td>605.788</td>
<td>Big Data Processing Using Hadoop</td>
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<tr>
<td>635.483</td>
<td>E-Business: Models, Architecture, Technologies and Infrastructure</td>
</tr>
</tbody>
</table>

### X. Cybersecurity

<table>
<thead>
<tr>
<th>Course Code</th>
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<tbody>
<tr>
<td>695.401</td>
<td>Foundations of Information Assurance</td>
</tr>
<tr>
<td>695.411</td>
<td>Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms</td>
</tr>
<tr>
<td>695.421</td>
<td>Public Key Infrastructure and Managing E-Security</td>
</tr>
<tr>
<td>695.422</td>
<td>Web Security</td>
</tr>
<tr>
<td>695.442</td>
<td>Intrusion Detection</td>
</tr>
<tr>
<td>695.443</td>
<td>Introduction to Ethical Hacking</td>
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<tr>
<td>695.701</td>
<td>Cryptology</td>
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<td>695.711</td>
<td>Java Security</td>
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<td>695.712</td>
<td>Authentication Technologies in Cybersecurity</td>
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<td>695.721</td>
<td>Network Security</td>
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<td>695.722</td>
<td>Covert Channels</td>
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<td>695.741</td>
<td>Information Assurance Analysis</td>
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<tr>
<td>695.742</td>
<td>Digital Forensics Technologies and Techniques</td>
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<tr>
<td>695.744</td>
<td>Reverse Engineering and Vulnerability Analysis</td>
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<td>695.791</td>
<td>Information Assurance Architectures and Technologies</td>
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</table>

### Special Topics

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<tbody>
<tr>
<td>605.801</td>
<td>Independent Study in Computer Science I</td>
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<tr>
<td>605.802</td>
<td>Independent Study in Computer Science II</td>
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</table>

### Graduate Courses for the Telecommunications and Networking Concentration

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<td>695.422</td>
<td>Web Security</td>
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<tr>
<td>695.701</td>
<td>Cryptology</td>
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<tr>
<td>695.721</td>
<td>Network Security</td>
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</tbody>
</table>

### Electrical and Computer Engineering Courses

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<tr>
<th>Course Code</th>
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<tbody>
<tr>
<td>525.408</td>
<td>Digital Telephony</td>
</tr>
<tr>
<td>525.414</td>
<td>Probability and Stochastic Processes for Engineers</td>
</tr>
<tr>
<td>525.416</td>
<td>Communication Systems Engineering</td>
</tr>
<tr>
<td>525.418</td>
<td>Antenna Systems</td>
</tr>
<tr>
<td>525.420</td>
<td>Electromagnetic Transmission Systems</td>
</tr>
<tr>
<td>525.438</td>
<td>Introduction to Wireless Technology</td>
</tr>
<tr>
<td>525.440</td>
<td>Satellite Communications Systems</td>
</tr>
<tr>
<td>525.441</td>
<td>Computer and Data Communication Networks I</td>
</tr>
<tr>
<td>525.707</td>
<td>Error Control Coding</td>
</tr>
<tr>
<td>525.708</td>
<td>Iterative Methods in Communications Systems</td>
</tr>
<tr>
<td>525.722</td>
<td>Wireless and Mobile Cellular Communications</td>
</tr>
<tr>
<td>525.723</td>
<td>Computer and Data Communication Networks II</td>
</tr>
</tbody>
</table>
Course Descriptions

605.201 Introduction to Programming Using Java
This course enables students without a background in software development to become proficient programmers who are prepared for a follow-on course in data structures. The Java language will be used to introduce foundations of structured, procedural, and object-oriented programming. Topics include I/O, data types, operators, operands, expressions, conditional statements, iteration, recursion, arrays, functions, parameter passing, and returning values. Students will also be introduced to classes, objects, object references, inheritance, polymorphism, and exception handling. Additional topics include file I/O, searching, sorting, Java Collections, and an introduction to Applets. Students will complete several programming assignments to develop their problem-solving skills and to gain experience in detecting and correcting software errors.

Prerequisites
One year of college mathematics.

Course Notes
Not for graduate credit.

Instructors: Chittargi, Ferguson, Qie, Shyamsunder, Smith

605.202 Data Structures
This course investigates abstract data types (ADTs), recursion, algorithms for searching and sorting, and basic algorithm analysis. ADTs to be covered include lists, stacks, queues, priority queues, trees, sets, and dictionaries. The emphasis is on the tradeoffs associated with implementing alternative data structures for these ADTs. There will be four or five substantial Java programming assignments.

Prerequisites
One year of college mathematics. 605.201 Introduction to Programming Using Java or equivalent.

Course Notes
Not for graduate credit.

Instructors: Chlan, Kann, Resch, Tjaden

Online Option Available

605.203 Discrete Mathematics
This course emphasizes the relationships between certain mathematical structures and various topics in computer science. Topics include set theory, graphs and trees, algorithms, propositional calculus, logic and induction, functions, relational algebra, and matrix algebra.

Prerequisites
Calculus is recommended. Since a mathematics course beyond one year of calculus is needed for admission to the graduate Computer Science program, students who lack this prerequisite can fulfill admission requirements by completing this course with a grade of A or B.

Course Notes
Not for graduate credit.

Instructor: Chlan

605.204 Computer Organization
This course examines how a computer operates at the machine level. Students will develop an understanding of the hardware/software interface by studying the design and operation of computing system components. In addition, students will program at the assembly language level to understand internal system functionality. Finally, students will become familiar with the machine representations of programs and data, as well as the influence of the underlying hardware system on the design of systems software such as operating systems, compilers, assemblers, and linkers and loaders.

Prerequisites
605.202 Data Structures is recommended.

Course Notes
Not for graduate credit.

Instructors: Kann, Malcom, Schappelle, Snyder, Whisnant

Online Option Available

605.205 Molecular Biology for Computer Scientists
This course is designed for students who seek to take bioinformatics courses but lack prerequisites in the biological sciences. The course covers essential aspects of biochemistry, cell biology, and molecular biology. Topics include the chemical foundations of life; cell organization and function; the structure and function of macromolecules; gene expression—transcription, translation, and regulation; biomembranes and transmembrane transport; metabolism and cellular energetics;
and signal transduction. The application of foundational concepts in developmental biology, neurobiology, immunology, and cancer biology is also introduced.

Course Notes
Not for graduate credit.

Instructor: Kumar

605.401 Foundations of Software Engineering
Fundamental software engineering techniques and methodologies commonly used during software development are studied. Topics include various life cycle models, project planning and estimation, requirements analysis, program design, construction, testing, maintenance and implementation, software measurement, and software quality. Emphasized are structured and object-oriented analysis and design techniques, use of process and data models, modular principles of software design, and a systematic approach to testing and debugging. The importance of problem specification, programming style, periodic reviews, documentation, thorough testing, and ease of maintenance are covered.

Instructors: Ligozio, Lindberg, Schappelle, Wichmann, Yufik

Online Option Available

605.402 Software Analysis and Design
This course emphasizes the concepts, methods, techniques, and tools for analyzing and designing complex software systems. Topics include design principles and strategies; engineering and analysis of software requirements; design models; software architectural design; architectural styles, qualities, attributes, notations, and documentation; architectural tradeoff analysis; formal methods for specification and analysis of software systems; and use of patterns in software design. Design for reuse and evolutionary considerations are also discussed. Students will gain critical insights in current best practices and be able to evaluate the contribution of popular methodologies to requirements analysis and software design.

Instructor: Olagbemiro

Online Option Available

605.404 Object Oriented Programming with C++
This course provides in-depth coverage of object-oriented programming principles and techniques using C++. Topics include classes, overloading, data abstraction, information hiding, encapsulation, inheritance, polymorphism, file processing, templates, exceptions, container classes, and low-level language features. The course briefly covers the mapping of UML design to C++ implementation and object-oriented considerations for software design and reuse. The course also relates C++ to GUI, databases, and real-time programming. Optional topics include the comparison of C++ with other OOP languages and techniques for interfacing C++ with Java.

Prerequisites
Knowledge of Java or C.

Instructors: Boon, Demasco, Ferguson, Pierson, Tjaden

605.405 Conceptual Design for High-Performance Systems
Recent data indicate that 80 percent of all new products or services in the United States fail within six months or fall significantly short of forecasted success. In the software industry, the average failure rate can be even higher, often entailing massive losses for both the developer, due to disappointing sales or excessive maintenance costs, and the user, due to learning difficulties and other performance problems. This course analyzes a set of issues critical to conceiving and executing a successful software product, with emphasis on complex dynamic applications. Topics are focused on three generic issues: (1) how to collect, organize, and formulate requirements encompassing both software and user performance; (2) how to define product-user interactions and design interfaces to satisfy performance requirements; and (3) how to assess the extent of requirements satisfaction (usability testing and analysis). In complex dynamic applications, user performance is particularly sensitive to design shortcomings. Discussion of such applications will concentrate on models of situation comprehension, image understanding, decision making under uncertainty, and other aspects of user performance that need to be considered to recognize and avoid typical design errors.

Instructor: Yufik

605.407 Agile Software Development Methods
This course emphasizes the quick realization of system value through disciplined, iterative, and incremental software development techniques and the elimination of wasteful practices. Students will study the full spectrum of agile methods, including Scrum, extreme programming, lean, Crystal methods, dynamic systems development method, feature-driven development, and Kanban. These methods promote teamwork, rich concise communication, and the frequent delivery of running, tested systems containing the highest-priority customer features. Agile methods are contrasted with common workplace practices and traditional methods such as Waterfall, CMMI, PMI/PMBOK, and RUP. Examples of agile adoption in industry are discussed. Additional subthemes in the course will include team dynamics, collaboration, software quality, and metrics for reporting progress.

Instructors: Menner, Olagbemiro

Online Option Available

605.408 Software Project Management
This course describes the key aspects of a software project. It begins with the job description of a software manager and then addresses those topics germane to successful software development management, including organizing the software development team; interfacing with other engineering organizations (systems engineering, quality assurance, configuration management, and test engineering); assessing development standards; selecting the best approach and tailoring the process model; estimating software cost and schedule; planning and documenting the plan; staffing the effort; managing soft-
ware cost and schedule during development; risk engineering; and continuous process improvement. Personnel management topics, including performance evaluations, merit planning, skills building, and team building, are also covered. This course introduces software engineers aspiring to become technical team leaders or software project managers to the responsibilities of these roles. For those engineers who have advanced to a software development leadership position, this course offers formal training in software project management.

**Prerequisites**
Three to five years’ technical work experience is recommended.

**Instructors:** Bowers, Winston

Online Option Available

**605.411 Foundations of Computer Architecture**
This course provides a detailed examination of the internal structure and operation of modern computer systems. Each of the major system components is investigated, including the following topics: the design and operation of the ALU, FPU, and CPU; microprogrammed vs. hardwired control, pipelining, and RISC vs. CISC machines; the memory system including caches and virtual memory; parallel and vector processing, multiprocessor systems and interconnection networks; superscalar and super-pipelined designs; and bus structures and the details of low-level I/O operation using interrupt mechanisms, device controllers, and DMA. The impact of each of these topics on system performance is also discussed. The instruction set architectures and hardware system architectures of different machines are examined and compared. The classical Von Neumann architecture is also compared and contrasted with alternative approaches such as data flow machines and neural networks.

**Instructors:** Beser, Kann, Malcom, Snyder, Whisnant

Online Option Available

**605.412 Operating Systems**
The theory and concepts related to operating system design are presented from both developer and user perspectives. Core concepts covered include process management, memory management, file systems, I/O system management including device drivers, distributed systems, and multi-user concepts including protection and security. Process management discussions focus on threads, scheduling, and synchronization. Memory management topics include paging, segmentation, and virtual memory. Students will examine how these concepts are realized in several current open-source operating systems, including Linux. Students will complete several assignments that require the design and implementation of operating system programs using a high-level language.

**Instructor:** Noble

Online Option Available

**605.414 System Development in the UNIX Environment**
This course describes how to implement software systems in a UNIX (POSIX-compliant) operating system environment. Students will discuss and learn the complexities, methodologies, and tools in the development of large systems that contain multiple programs. Topics include an overview of the UNIX system and its general-purpose tools, advanced makefile usage, UNIX system calls, UNIX process management, threads, and basic and advanced interprocess communication. Additional topics include source code configuration control, Perl, and debugging techniques.

**Prerequisites**
Familiarity with UNIX, experience with C++ or C.

**Instructors:** Barrett, Ching, Noble

Online Option Available

**605.415 Compiler Design**
This course explores the principles, algorithms, and data structures involved in the design and construction of compilers. Topics include finite-state machines, lexical analysis, context-free grammars, push-down parsers, LR and LALR parsers, other parsing techniques, symbol tables, error recovery, and an introduction to intermediate code generation. Students are provided a skeleton of a functioning compiler in C to which they can add functionality. Several skeletal implementations in C++ as well as a back-end interface to Jasmin are also available. As Jasmin assembles to Java Byte Code, students can develop compilers that target any platform with a Java Virtual Machine, and by the end of the course, students will have developed a compiler for a subset of C.

**Instructor:** Ferguson

**605.416 Multiprocessor Architecture and Programming**
This course addresses how to utilize the increasing hardware capabilities of multiprocessor computer architecture’s high-performance computing platforms for software development. The famous Moore’s Law is still alive, although it is now realized from increasing the number of CPU cores instead of increasing CPU clock speed. This course describes the differences between single-core and multi-core systems and addresses the impact of these differences in multiprocessor computer architectures and operating systems. Parallel programming techniques to increase program performance by leveraging the multiprocessor system, including multi-core architectures, will be introduced. Additional topics include program performance analysis and tuning, task parallelism, synchronization strategies, shared memory access and data structures, and task partition techniques. The course encourages hands-on experience with projects selected by the student.

**Instructor:** Zheng
605.420 Algorithms for Bioinformatics

This follow-on course to data structures (e.g., 605.202) provides a survey of computer algorithms, examines fundamental techniques in algorithm design and analysis, and develops problem-solving skills required in all programs of study involving computer science. Topics include advanced data structures (red-black and 2-3-4 trees, union-find), algorithm analysis and computational complexity (recurrence relations, big-O notation, introduction to NP-completeness), sorting and searching, design paradigms (divide and conquer, greedy heuristic, dynamic programming), and graph algorithms (depth-first and breadth-first search, minimum spanning trees,). Advanced topics are selected from among the following: multi-threaded algorithms, matrix operations, linear programming, string matching, computational geometry, and approximation algorithms. The course will draw on applications from Bioinformatics. This course does not satisfy the foundation course requirement for Computer Science or Cybersecurity. Students cannot earn credit for both 605.420 and 605.421.

**Prerequisites**
605.202 Data Structures or equivalent.

**Instructor:** Chlan

Online Option Available

605.421 Foundations of Algorithms

This follow-on course to data structures (e.g., 605.202) provides a survey of computer algorithms, examines fundamental techniques in algorithm design and analysis, and develops problem-solving skills required in all programs of study involving computer science. Topics include advanced data structures (red-black and 2-3-4 trees, union-find), recursion and mathematical induction, algorithm analysis and computational complexity (recurrence relations, big-O notation, NP-completeness), sorting and searching, design paradigms (divide and conquer, greedy heuristic, dynamic programming, amortized analysis), and graph algorithms (depth-first and breadth-first search, minimum spanning trees, network flow). Advanced topics are selected from among the following: randomized algorithms, information retrieval, string and pattern matching, and computational geometry.

**Prerequisites**
605.202 Data Structures or equivalent. 605.203 Discrete Mathematics or equivalent is recommended.

**Instructors:** Boon, Lew, Maurer, Rodriguez, Sadowsky, Sheppard

Online Option Available

605.422 Computational Signal Processing

This course introduces computational aspects of signal processing, specifically algorithms for processing digital signals, methods for the design and analysis of signal processing algorithms, architectures for signal processing systems, and areas of application. Topics include signal analysis (signal definition, time and frequency domains, sampling and digitizing, noise and error), systems for signal processing (filters and nonfilters, correlation, adaptation), and algorithms and architectures (fast Fourier transforms, fast convolution, digital filtering, interpolation and resampling, digital signal processors, function evaluation, and computational complexity). Areas of application include communication systems, speech signal processing, and digital media.

**Prerequisites**
Knowledge of complex numbers and linear algebra.

**Instructor:** Sadowsky

605.423 Applied Combinatorics and Discrete Mathematics

Combinatorics and discrete mathematics are becoming increasingly important fields of mathematics because of their extensive applications in computer science, statistics, operations research, and engineering. The purpose of this course is to teach students to model, analyze, and solve combinatorial and discrete mathematical problems. Topics include elements of graph theory, the pigeonhole principle, counting methods, generating functions, recurrence relations and their solution, and the inclusion-exclusion formula. Emphasis is on the application of the methods to problem solving.

**Course Notes**
This course is the same as 625.417 Applied Combinatorics and Discrete Mathematics.

**Instructor:** Whisnant

605.424 Logic: Systems, Semantics, and Models

The use of predicate logic for modeling information systems is widespread and growing. Knowledge representation, for example, has long been important in artificial intelligence applications and is now emerging as a critical component of semantic web applications. Similarly, predicate logic is the basis for ontologies and inferential knowledge bases. This course teaches the fundamentals of propositional and predicate logic, with an emphasis on semantics. Modal logic is introduced as a tool to manage non-truth-functional systems, and dynamic logic is introduced to manage potentially inconsistent systems, such as may arise in merging disparate databases or in combining diagnostic models of related systems.

**Course Notes**
This course may be counted toward a three-course track in Database Systems and Knowledge Management.

**Instructor:** Waddell

605.426 Image Processing

Fundamentals of image processing are covered, with an emphasis on digital techniques. Topics include digitization, enhancement, segmentation, the Fourier transform, filtering, restoration, reconstruction from projections, and image analysis including computer vision. Concepts are illustrated by laboratory sessions in which these techniques are applied.
to practical situations, including examples from biomedical image processing.

**Prerequisites**

Familiarity with Fourier transforms.

**Instructor:** Byrd

605.427  **Computational Photography**

Computational photography is an emerging research area at the intersection of computer graphics, image processing, and computer vision. As digital cameras become more popular and collections of images continue to grow, we’ve seen a surge in interest in effective ways to enhance photography and produce more realistic images through the use of computational techniques. Computational photography overcomes the limitations of conventional photography by analyzing, manipulating, combining, searching, and synthesizing images to produce more compelling, rich, and vivid visual representations of the world. This course will introduce the fundamental concepts of image processing, computer vision, and computer graphics, as well as their applications to photography. Topics include image formation, filtering, blending, and completion techniques. In addition, the course will discuss different image analysis and rendering techniques including texture analysis, morphing, and non-photorealistic rendering.

**Instructor:** Caban

605.428  **Applied Topology**

The course is both an introduction to topology and an investigation of various applications of topology in science and engineering. Topology, simply put, is a mathematical study of shapes, and it often turns out that just knowing a rough shape of an object (whether that object is as concrete as platonic solids or as abstract as the space of all paths in large complex networks) can enhance one’s understanding of the object. We will start with a few key theoretical concepts from point-set topology with proofs, while letting breadth take precedence over depth, and then introduce key concepts from algebraic topology, which attempts to use algebraic concepts, mostly group theory, to develop ideas of homotopy, homology, and cohomology, which render topology “computable.” Finally, we discuss a few key examples of real-world applications of computational topology, an emerging field devoted to the study of efficient algorithms for topological problems, especially those arising in science and engineering, which builds upon classical results from algebraic topology as well as algorithmic tools from computational geometry and other areas of computer science. The questions we like to ask are: Do I know the topology of my network? What is a rough shape of the large data set that I am working with? (is there a logical gap?) Will the local picture of a part of the sensor field I am looking at give rise to a consistent global common picture?

**Prerequisites**

Multivariate calculus, linear algebra and matrix theory (e.g., 625.409), and an undergraduate-level course in probability and statistics.

**Course Notes**

This course is the same as 625.487 Applied Topology.

**Instructor:** Chin

605.429  **Programming Languages**

This course compares and contrasts a wide variety of features of at least 12 programming languages, including programming language history; formal methods of describing syntax and semantics; names, binding, type checking, and scopes; data types; expressions and assignment statements; statement-level control structures; design and implementation of subprograms; exception handling; and support for object oriented programming. Students will also learn and write four-week projects in three programming languages (e.g., Python, Perl, and C#).

**Instructor:** Mauer

605.431  **Cloud Computing**

Cloud computing helps organizations realize cost savings and efficiencies while modernizing and expanding their IT capabilities without spending capital resources up front. Cloud-based infrastructure is rapidly scalable, secure, and accessible over the Internet—you pay only for what you use. So, enterprises worldwide, big and small, are moving toward cloud-computing solutions for meeting their computing needs, including the usage of Infrastructure as a Service (IaaS) and Platform as a Service (PaaS). We have also seen a fundamental shift from shrink-wrapped software to Software as a Service (SaaS) in data centers across the globe. Moreover, providers such as Amazon, Google, and Microsoft have opened their data centers to third parties by providing low-level services such as storage, computation, and bandwidth. This trend is creating the need for a new kind of enterprise developer, architect, QA professional—someone who understands and can effectively use cloud-computing solutions. In this course, we discuss critical cloud topics such as virtualization, service models, elastic computing, big data, distributed databases, orchestration, security, and new trends that are enabling the cloud-computing platforms. We also cover the architecture and the design of existing deployments, as well as the services and the applications they offer. The format of this course will be a mix of lectures, hands-on demos, and student presentations. On completing this course, students will gain a deeper understanding of what cloud computing is and the various technologies that make up cloud computing, with hands-on experience configuring and deploying apps, in the cloud.

**Instructor:** Staff

605.432  **Graph Analytics**

This course introduces algorithms, architectures, and techniques used to address the problem of large-scale graph ana-
lytics. Graphs provide a flexible data structure that facilitates fusion of disparate data sets. Popularity of graphs has shown a steady growth, with the development of Internet, cyber, and social networks. While graphs provide a flexible data structure, processing of large graphs remains a challenging problem. This course will start by introducing graphs, their properties, and example applications. Discussion will include mapping of relational data bases to graphs. Distributed storage and processing architectures such as Accumulo Map/Reduce, Pregel (Giraph), etc., that support graph analytics will be examined. Common classes of algorithms used for graph analytics will be studied to identify which architectures would best support the algorithms. For example, certain classes of algorithms combined with large-scale data would be best served by Giraph, while other classes of algorithmscombined with large-scale data would be best served by Accumulo, etc. There will be hands-on programming assignments of graph algorithms. The course will be a blend of graph analytics theory, graph architectures, and graph systems that support the analytics. By the end of the course, students will get a flavor of which architectures and approaches are the best choices for different classes of graph algorithms with different data sizes.

**Instructor:** Staff

**605.441 Principles of Database Systems**

This course examines the underlying concepts and theory of database management systems. Topics include database system architectures, data models, query languages, conceptual and logical database design, physical organization, and transaction management. The entity-relationship model and relational model are investigated in detail, object-oriented databases are introduced, and legacy systems based on the network and hierarchical models are briefly described. Mappings from the conceptual level to the logical level, integrity constraints, dependencies, and normalization are studied as a basis for formal design. Theoretical languages such as the relational algebra and the relational calculus are described, and high-level languages such as SQL and QBE are discussed. An overview of file organization and access methods is provided as a basis for discussion of heuristic query optimization techniques. Finally, transaction processing techniques are presented with a specific emphasis on concurrency control and database recovery.

**Instructors:** Kang, Liu

Online Option Available

**605.443 The Semantic Web**

The Semantic Web is an activity by the WWW Consortium to create a large set of XML-based languages, along with information on how various tags relate to real-world objects and concepts. This course covers Semantic Web technologies, including RDF (Resource Description Format, a structure for describing and interchanging metadata on the web) and OWL (Web Ontology Language), with domain-specific standards and ontologies (formal specifications of how to represent objects and concepts). Representative applications of RDF, OWL, and ontologies will be discussed. Students will complete a Semantic Web project in an application area of interest to them. Examples will be drawn from several application areas.

**Prerequisites**

605.444 XML Design Paradigms or equivalent.

**Course Notes**

This course may be counted toward a three-course track in Bioinformatics.

**Instructor:** Cott

Online Option Available

**605.444 XML Design Paradigms**

The course explores understanding the tradeoffs among XML grammars and XML techniques to solve different classes of problems. Topics include optimization of XML grammars for different XML technologies; benefits of using different XML schema languages; tradeoffs in using different parsing approaches; benefits of parsing technology vs. XML query; the role of Web 2.0 to deliver functionality through various web services approaches; exploiting XML to drive audio, visual, and tactile displays; the role of XML in multiplying the power of standard web browser technologies; and the role of Web 3.0 to deliver Semantic Web functionality. XML technologies that will be covered include XML Schema, XPath, XSLT, SAX, DOM, XQuery, SOAP, WSDL, JAX-B, JAX-WS, REST, RDF, and OWL.

**Prerequisites**

605.481 Principles of Enterprise Web Development or equivalent Java experience.

**Course Notes**

Formerly 635.444 XML: Technology and Applications.

**Instructors:** Chittargi, Silberberg

Online Option Available

**605.445 Artificial Intelligence**

The incorporation of advanced techniques in reasoning and problem solving into modern, complex systems has become pervasive. Often, these techniques fall within the realm of artificial intelligence. This course focuses on artificial intelligence from an agent perspective and explores issues of knowledge representation and reasoning. Students will participate in lectures and discussions on various topics, including heuristic and stochastic search, logical and probabilistic reasoning, planning, learning, and perception. Advanced topics will be selected from areas such as robotics, vision, natural language processing, and philosophy of mind. Students will complete problem sets and small software projects to gain hands-on experience with the techniques and issues covered.

**Instructor:** Butcher

Online Option Available
605.446 Natural Language Processing
This course introduces the fundamental concepts and techniques of natural language processing (NLP). Students will gain an in-depth understanding of the computational properties of natural languages and the commonly used algorithms for processing linguistic information. The course examines NLP models and algorithms using both the traditional symbolic and the more recent statistical approaches. It includes treatment of natural languages at the lexical, syntactic, semantic, and pragmatic levels. The course also covers the development of modern NLP systems using statistical and machine learning techniques.

Prerequisites
605.445 Artificial Intelligence or equivalent.

Instructor: Kumar

605.447 Neural Networks
This course provides an introduction to concepts in neural networks and connectionist models. Topics include parallel distributed processing, learning algorithms, and applications. Specific networks discussed include Hopfield networks, bidirectional associative memories, perceptrons, feedforward networks with back propagation, and competitive learning networks, including self-organizing and Grossberg networks. Software for some networks is provided.

Prerequisites
Multivariate calculus and linear algebra

Course Notes
This course is the same as 625.438 Neural Networks.

Instructor: Fleischer

605.448 Data Science
This course will cover the core concepts and skills in the emerging field of data science. The data science pipeline will be explored in depth: problem formulation, the acquisition and cleaning of multisource data sets, data summarization and exploratory analysis, model building, analysis and evaluation, and the presentation of results. Topics covered will include types of data sources and databases, web scraping and APIs, text parsing and regular expressions, experimental design, summary statistics, data visualizations, supervised (regression, logistic regression, decision trees, random forests, etc.) and unsupervised (clustering, network analysis) machine learning techniques, model evaluation and testing, and the construction of web applications and reports to present results. Students will gain direct experience in solving the programming and analytical challenges associated with data science through short assignments and a larger project.

Prerequisites
Programming experience in Python is recommended.

Instructor: Butcher

605.451 Principles of Computational Biology
This course is an interdisciplinary introduction to computational methods used to solve important problems in DNA and protein sequence analysis. The course focuses on algorithms but includes material to provide the necessary biological background for science and engineering students. Algorithms to be covered include dynamic programming for sequence alignment, such as Smith-Waterman, FASTA, and BLAST; hidden Markov models, such as the forward, Viterbi, and expectation maximization algorithms; a range of gene-finding algorithms; phylogenetic tree construction; and clustering algorithms.

Prerequisites
Familiarity with probability and statistics; working knowledge of Java, C++, or C; 605.205 Molecular Biology for Computer Scientists or a course in molecular biology; and either a course in cell biology or biochemistry.

Instructors: Przytycka and Rogozin, Qie

605.452 Biological Databases and Database Tools
The sequencing of the human genome and intense interest in proteomics and molecular structure have resulted in an explosive need for biological databases. This course surveys a wide range of biological databases and their access tools and enables students to develop proficiency in their use. Databases introduced include genome and sequence databases such as GenBank and Ensemble, as well as protein databases such as PDB and SWISS-PROT. Tools for accessing and manipulating sequence databases such as BLAST, multiple alignment, Perl, and gene finding tools are covered. Specialized databases such as KEGG and HapMap are surveyed for their design and use. The course also focuses on the design of biological databases and examines issues related to heterogeneity, interoperability, complex data structures, object orientation, and tool integration. Students will create their own small database as a course project and will complete homework assignments using biological databases and database tools.

Prerequisites
605.205 Molecular Biology for Computer Scientists or equivalent. 605.441 Principles of Database Systems or 410.634 Practical Computer Concepts for Bioinformatics recommended.

Instructor: Hobbs

Online Option Available

605.453 Computational Genomics
This course focuses on current problems of computational genomics. Students will explore bioinformatics software, discuss bioinformatics research, and learn the principles underlying a variety of bioinformatics algorithms. The emphasis is on algorithms that use probabilistic and statistical approaches. Topics include analyzing eukaryotic, bacterial, and viral genes and genomes, genome sequencing and assembling, finding genes in genomes and identifying their biological functions,
predicting regulatory sites, and assessing gene and genome evolution.

**Prerequisites**
605.205 Molecular Biology for Computer Scientists or equivalent and familiarity with probability and statistics.

**Instructor:** Ermolaeva
Online Option Available

**605.456 Computational Drug Discovery and Development**
Recent advances in bioinformatics and drug discovery platforms have brought us significantly closer to the realization of rational drug design and development. Across the pharmaceutical industry, considerable effort is being invested in developing experimental and translational medicine, and it is starting to make a significant impact on the drug discovery process itself. This course examines the major steps of the evolving modern drug discovery platforms, the computational techniques and tools used during each step of rational drug discovery, and how these techniques facilitate the integration of experimental and translational medicine with the discovery/development platforms. The course will build on concepts from a number of areas including bioinformatics, computational genomic/proteomics, in silico system biology, computational medicinal chemistry, and pharmaceutical biotechnology. Topics covered in the course include comparative pharmacogenomics, protein/antibody modeling, interaction and regulatory networks, QSAR/pharmacophores, ADME/toxicology, and clinical biomarkers. Relevant mathematical concepts are developed as needed in the course.

**Prerequisites**
605.205 Molecular Biology for Computer Scientists or equivalent.

**Instructor:** Kumar
Online Option Available

**605.462 Data Visualization**
This course explores the underlying theory and practical concepts in creating visual representations of large amounts of data. It covers the core topics in data visualization: data representation, visualization toolkits, scientific visualization, medical visualization, information visualization, flow visualization, and volume rendering techniques. The related topics of applied human perception and advanced display devices are also introduced.

**Prerequisites**
Experience with data collection/analysis in data-intensive fields or background in computer graphics (e.g., 605.467 Computer Graphics ) is recommended.

**Instructor:** Chian

**605.467 Computer Graphics**
This course examines the principles of computer graphics, with a focus on the mathematics and theory behind 2D and 3D graphics rendering. Topics include graphics display devices, graphics primitives, 2D and 3D transformations, viewing and projection, color theory, visible surface detection and hidden surface removal, lighting and shading, and object definition and storage methods. Practical application of these concepts is emphasized through laboratory exercises and code examples. Laboratory exercises use the C++ programming language and OpenGL on a PC.

**Prerequisites**
Familiarity with linear algebra.

**Instructor:** Nesbitt

**605.471 Principles of Data Communications Networks**
This course provides an introduction to the field of data communications and computer networks. The course covers the principles of data communications, the fundamentals of signaling, basic transmission concepts, transmission media, circuit control, line sharing techniques, physical and data link layer protocols, error detection and correction, data compression, network security techniques, common carrier services and data networks, and the mathematical techniques used for network design and performance analysis. Potential topics include analog and digital signaling; data encoding and modulation; Shannon channel capacity; FDM, TDM, and STDM multiplexing techniques; inverse multiplexing; analog and digital transmission; PCM encoding and T1 transmission circuits; CRC error detection and Hamming and Viterbi error correction techniques; Huffman and Lempel-Ziv data compression algorithms; symmetric key and public key encryption, authentication and digital signatures, PKI and key distribution, secure e-mail and PGP; circuit, packet, and cell switching techniques; TCP/IP protocols and local area networks; network topology optimization algorithms, reliability and availability, and queuing analysis; and circuit costing.

**Instructors:** Boules, Nieporent, Smith
Online Option Available

**605.472 Computer Network Architectures and Protocols**
This course provides a detailed examination of the conceptual framework for modeling communications between processes residing on independent hosts, as well as the rules and procedures that mediate the exchange of information between two communication processes. The Open Systems Interconnection Reference Model (OSIRM) is presented and compared with TCP/IP and other network architectures. The service definitions and protocols for implementing each of the seven layers of the Reference Model using both OSI and TCP/IP protocols are analyzed in detail. Internetworking among heterogeneous subnets is described in terms of addressing and routing, and techniques for identifying different protocol suites sent over the subnets are explained. The protocol header encoding rules are examined, and techniques for parsing protocol headers are analyzed. The application layer
sub-architecture for providing common application services is described, and interoperability techniques for implementing multiprotocol internets are presented. Topics include layering, encapsulation, SAPs, and PDUs; sliding window protocols, flow and error control; virtual circuits and datagrams; routing and congestion control algorithms; interworking; NSAP and IP addressing schemes; CLNP, IPv4, and the new IPv6 internet protocols; RIP, OSPF, ES-IS, and IS-IS routing protocols; TP4 and TCP transport protocols; dialog control, activity management, and the session layer protocol; ASN.1 encoding rules and the presentation layer protocol; application layer structure and the ACSE, CCR, ROSE, and RTSE common application service elements; OSI VT, FTAM, and MOTIS application protocols; TCP/IP TELNET, FTP, and SMTP application protocols; OSI transitioning tools; multiprotocol networks; and encapsulation, tunneling, and convergence techniques.

**Prerequisites**

605.471 Principles of Data Communications Networks.

**Instructor:** Nieporent

### 605.473 High-Speed Networking Technologies

Network evolution has been driven by the need to provide multimedia (i.e., voice, data, video, and imagery) communications in an efficient and cost-effective manner. Data, video, and imagery particularly warrant high-speed and high-capacity network technologies. Moreover, the emergence of the Internet and Internet-based services such as the World Wide Web (WWW) and the current trend toward converging voice and video services have accelerated the demand for high-speed network technologies. This course provides an in-depth understanding of various existing and emerging high-speed networking technologies. Specific technologies covered include digital transmission system, digital subscriber line (DSL), integrated service digital network (ISDN), frame relay, asynchronous transfer mode (ATM), synchronous optical network (SONET), wavelength division multiplexing (WDM), dense WDM (DWDM), and optical networking.

**Prerequisites**

605.471 Principles of Data Communications Networks.

**Course Notes**

Formerly 605.773 High-Speed Networking Technologies.

**Instructor:** Krishman

Online Option Available

### 605.474 Network Programming

Emphasis is placed on the theory and practice associated with the implementation and use of the most common process-to-process communications associated with UNIX. The inter-process communications comprise both local and distributed architectures. The distributed communications protocols include those most widely implemented and used: the worldwide Internet protocol suite [the Transmission Control Protocol/Internet Protocol (TCP/IP), and the U.S. government-mandated International Organization for Standardization (ISO) protocol suite]. Practical skills are developed, including the ability to implement and configure protocol servers (daemons) and their clients. Students are expected to have working knowledge of UNIX.

**Prerequisites**

605.471 Principles of Data Communications Networks or 605.414 System Development in the UNIX Environment.

**Instructor:** Noble

### 605.475 Protocol Design and Simulation

This course covers the formal design, specification, and validation of computer and network protocols. Design, implementation, and verification of protocols will be illustrated using the latest simulation tools, such as OPNET and NS2. Protocol examples include the latest wired and wireless networks, such as the IEEE 802.X family, as well as protocols in VoIP, Web 2.0, and network security. The course focuses on protocol specification, structured protocol design, protocol models, and protocol validation. Students will gain hands-on experience using simulation tools to design, validate, and assess protocols.

**Prerequisites**

605.471 Principles of Data Communications Networks or equivalent.

**Instructor:** Zheng

### 605.477 Internetworking with TCP/IP I

This course investigates the underlying technology of the Internet. The presentation begins with a survey of distributed applications operating over the Internet, including the web, electronic mail, VoIP, instant messaging, file transfers, and peer-to-peer file sharing. The course investigates the details of the Internet architecture and the TCP/IP protocol suite, covering the protocols that provide communications services to end systems and the management and control protocols that create the Internet from disparate underlying networks and technologies. Communications-related protocols analyzed in detail include the foundational Internet Protocol (IP), the connection-oriented reliable Transmission Control Protocol (TCP), the connectionless User Datagram Protocol (UDP), and the Real-Time Protocol (RTP) for streaming media. To allow the student to understand the control and management of the Internet, the course analyzes protocols that support naming (DNS), addressing and configuration (DHCP), management (SNMP), and the dynamic IP routing protocols RIP, OSPF, and BGP.

**Prerequisites**

605.471 Principles of Data Communications Networks.

**Instructors:** DeSimone, Scott

Online Option Available
605.478  Cellular Communications Systems
This course introduces the principles of cellular communications systems. Second-generation (2G) digital, mobile cellular, and personal communications systems (PCS) concepts are discussed, including the cellular concept, frequency reuse, propagation, multiple access, power control, handoff, and traffic engineering. Limitations of 2G cellular systems are described, and improvements proposed by 2.5G and 3G cellular standards to support high-rate data services are presented. Emphasis is placed on layer 2 and above, such as retransmission protocols, medium access control, call processing, interworking, radio resource management (e.g., frequency, time, and power), QoS provisioning, scheduling, and mobility management (e.g., mobile IP). The Wireless Local Area Networking IEEE 802.11 WLAN, the Wireless Metropolitan Area Networking IEEE 802.16 (Fixed and Mobile) WiMAX, and Wireless Personal Area Networking IEEE 802.15 Bluetooth are discussed for their roles in 3G. The Media Independent Handover standard IEEE 802.21 (e.g., integrating WLAN and 3G cellular networks to provide session/service continuity) is also introduced. Cellular standards are examined, including U.S. 2G code-division multiple access (CDMA) IS-95A, 2.5G IS-95B, 3G cdma2000 1x, and 1x-EVDO. Other standards discussed include European 2G time-division multiple access (TDMA) Global System for Mobile communication (GSM), 2.5G General Packet Radio Service (GPRS), 2.5G Enhanced Data Rates for GSM Evolution (EDGE), 3G wideband-CDMA (W-CDMA), and 4G Long Term Evolution (LTE).
Prerequisites
605.471 Principles of Data Communications Networks.
Instructors: Misra, Shy

605.481  Principles of Enterprise Web Development
This course examines three major topics in the development of applications for the World Wide Web. The first is website development using HTML and related standards. The second is the implementation of client-side applications using the Java programming language, including user interface development, asynchronous event handling, multithreaded programming, and network programming. Distributed object protocols via RMI or CORBA and distributed database access via JDBC may also be introduced. The third topic is the design of server-side web applications, for which students will examine the underlying web protocol (HTTP), the development of client-side interfaces (e.g., via HTML forms), and the implementation of server-side programs (e.g., via Java servlets or traditional CGI).
Instructors: Chittargi, R. Evans, Shyamsunder, Spiegel

605.484  Agile Development with Ruby on Rails
Modern web applications are expected to facilitate collaboration, with user participation being a significant facet of the system. Components such as wikis, blogs, and forums are now commonplace. While feature sets continue to expand, there is continuing pressure to develop and deploy capabilities more quickly to enable organizations to remain competitive. This pressure has led to the development of languages and frameworks geared toward rapid prototyping, with Ruby on Rails being the most popular. Ruby on Rails is a model-view-controller (MVC) framework that enables efficient application development and deployment. Techniques such as convention over configuration and object-relational mapping with ActiveRecord along with enhanced AJAX support offer a simple environment with significant productivity gains. This code-intensive course introduces Ruby on Rails, the patterns it implements, and its applicability to the rapid development of collaborative applications.
Prerequisites
605.481 Principles of Enterprise Web Development or equivalent.
Instructor: Hazins

605.486  Mobile Application Development for the Android Platform
This project-oriented course will investigate the issues surrounding application development for mobile platforms. First, we will look at techniques for building applications that adapt to the ways in which mobile apps differ from traditional desktop or web-based apps: constrained resources, small screen sizes, varying display resolutions, intermittent network connectivity, specialized sensors, security restrictions, and so forth. Second, we will look at best practices for making mobile applications flexible: using XML-based layouts, managing multimedia, storing user data, networking via Bluetooth and WiFi, determining device location and orientation, deploying applications, and gracefully handling shutdowns and restarts to the application. Optional topics may include embedding web components with WebKit, showing maps with the Google Maps plug-in, and storing local data with SQLite. Students will be provided links to download free tools for building and testing Android apps; there is no requirement that students own a physical Android device.
Prerequisites
605.481 Principles of Enterprise Web Development or equivalent.
Instructor: Stanchfield

605.701  Software Systems Engineering
Software systems engineering applies engineering principles and the system view to the software development process. The course focuses on the engineering of complex systems that have a strong software component. This course is based on the philosophy that the key to engineering a good software system lies just as much in the process that is followed as in the purely technical regime. The course will show how good a software development process is and how to make a software process better by studying successful techniques that have
been employed to produce correct software systems within budget. Topics are explored in a sequence designed to reflect the way one would choose to implement process improvements. These topics include steps to initiate process change, methods to establish control over the software process, ways to specify the development process, methods for quantitative process control, and how to focus on problem prevention. Students will prepare term projects.

**Prerequisites**
One software engineering course beyond 605.401 Foundations of Software Engineering.

**Instructors:** Siegel and Donaldson, White

**Online Option Available**

### 605.702 Service-Oriented Architecture

Service-Oriented Architecture (SOA) is a way to organize and use distributed capabilities that may be controlled by different owners. SOA provides a uniform means to offer, discover, interact with, and use capabilities to produce desired effects consistent with specified preconditions and requirements. This course describes SOA concepts and design principles, interoperability standards, security considerations, runtime infrastructure, and web services as an implementation technology for SOA. Given the focus on shared capabilities, SOA involves more than technology. Therefore, additional topics will include the impact of SOA on culture, organization, and governance.

**Prerequisites**
605.401 Foundations of Software Engineering and 605.704 Object-Oriented Analysis and Design or equivalent experience are highly recommended.

**Instructors:** John, Pole

### 605.704 Object-Oriented Analysis and Design

This course describes fundamental principles of object-oriented modeling, requirements development, analysis, and design. Topics include specification of software requirements; object-oriented analysis approaches, including dynamic and static modeling with the Unified Modeling Language (UML v2); object-oriented design; object-oriented reuse, including design patterns; and software implementation concerns. Optional topics include the Systems Modeling Language (SysML), Object-Oriented Systems Engineering Methodology (OOSEM), managing object-oriented projects, and the Object Constraint Language (OCL).

**Prerequisites**
Experience in object-oriented programming using a language such as Java or C++.

**Instructors:** Demasco, Ferguson, Pierson, Schappelle, Schepers

### 605.705 Software Safety

This course describes how to develop and use software that is free of imperfections that could cause unsafe conditions in safety-critical systems. Systems engineering and software engineering techniques are described for developing “safe-software,” and case studies are presented regarding catastrophic situations that resulted from software and system faults that could have been avoided. Specific techniques of risk analysis, hazard analysis, fault tolerance, and safety tradeoffs within the software engineering paradigm are discussed.

**Instructor:** Giezel

### 605.707 Design Patterns

Software patterns encapsulate the knowledge of experienced software professionals in a manner that allows developers to apply that knowledge to similar problems. Patterns for software are analogous to the books of solutions that enable electrical engineers and civil engineers to avoid having to derive every new circuit or bridge design from first principles. This course will introduce the concept of software patterns and explore the wide variety of patterns that may be applied to the production, analysis, design, implementation, and maintenance of software. The format of the course will emphasize the discussion of patterns and their application. Each student will be expected to lead a discussion and to actively participate in others. Students will also be expected to introduce new patterns or pattern languages through research or developed from their own experience. Programming exercises performed outside of class will be used enhance discussion and illustrate the application of patterns.

**Prerequisites**
605.404 Object Oriented Programming with C++ or permission of instructor.

**Instructors:** Lindberg, Stanchfield

### 605.708 Tools and Techniques of Software Project Management

This course examines tools and techniques used to lead software-intensive programs. Techniques for RFP analysis and proposal development are explored, and techniques of size estimation (function points, feature points, and lines-of-code estimation) and the use of models such as COCOMO to convert size to effort and schedule are described. In addition, conversion of estimated effort to dollars and the effects of fringe, overhead, skill mix profiles, and staffing profiles on total dollar cost are explained. Moreover, techniques for estimating effort and planning the COTS intensive development programs are described, and tools and techniques for measuring process maturity and process efficiency (e.g., CMMi, Lean, Six Sigma, and Kaizen) are addressed. The course also investigates the formation and management of virtual teams, as well as techniques that can be used to ensure success in this environment. Finally, the course addresses topics that require collaboration between the project manager and human resources, such as personnel retention strategies, managing unsatisfactory performance, and formal mentoring programs.

**Prerequisites**
Three to five years’ technical work experience is recommended.

**Instructor:** Winston

**Online Option Available**
605.709 Seminar in Software Engineering
This course examines the underlying concepts and latest topics in software engineering. Potential topics include use of effective open-source software development techniques such as agile methods, automated code generation, testing strategies, development tools and environments, patterns, metrics in the development process, successful teamwork, and training aspects of CMMI. Each student will select and report on a software engineering topic, independently research a topic, and prepare a paper describing a major software engineering issue. The course is taught using a seminar format in which significant portions of the class period are set aside for students to lead and actively participate in discussions.

Prerequisites
One software engineering course beyond 605.401 Foundations of Software Engineering or permission of the instructor.

Instructor: Pole

605.713 Robotics
This course introduces the fundamentals of robot design and development with an emphasis on autonomy. Robot design, navigation, obstacle avoidance, and artificial intelligence will be discussed. Topics covered in robot design include robot structure, kinematics and dynamics, the mathematics of robot control (multiple coordinate systems and transformations), and designing for autonomy. Navigation topics include path planning, position estimation, sensors (e.g., vision, ultrasonics, and lasers), and sensor fusion. Obstacle avoidance topics include obstacle characterization, object detection, sensors and sensor fusion. Topics to be discussed in artificial intelligence include learning, reasoning, and decision making. Students will deepen their understanding through several assignments and the term-long robot development project.

Instructor: Lapin

605.715 Software Development for Real-Time Embedded Systems
This course examines the hardware and software technologies behind real-time, embedded computer systems. From smart kitchen appliances to sophisticated flight control for airliners, embedded computers play an important role in our everyday lives. Hardware topics include microcomputers and support devices (e.g., flash, ROM, DMA, timers, clocks, A/D, and D/A), as well as common applications (e.g., servo and stepper motor control, automotive sensors, and voice processing). Software topics focus on unique aspects of embedded programming and include interrupts, real-time control, communication, common design patterns, and special test considerations. The course also explores the unique tools that are used to develop and test embedded systems. Several labs using a popular robotics development system and Java reinforce the concepts presented.

Prerequisites
Programming experience with Java.

Instructor: Ferguson

605.716 Modeling and Simulation of Complex Systems
This course focuses on the application of modeling and simulation principles to complex systems. A complex system is a large-scale nonlinear system consisting of interconnected or interwoven parts (such as a biological cell, the economy, or an ecological system). The course begins with an overview of complex systems, followed by modeling and simulation techniques based on nonlinear differential equations, networks, stochastic models, cellular automata, and swarm-like systems. Existing software systems will be used to illustrate systems and provide practical experience. During the semester, each student will complete a modeling project of a complex system. While this course is intended for computer science or engineering students interested in modeling any complex system, it may also be taken by bioinformatics students interested in modeling complex biological systems. Students interested in bioinformatics will study a parallel track exposing them to existing whole-cell modeling tools such as E-Cell, COPASI, and BioSpice.

Prerequisites
Knowledge of elementary probability and statistics and previous exposure to differential equations. Students applying this course to the MS in Bioinformatics should also have completed at least one Bioinformatics course prior to enrollment.

Course Notes
This course may be counted toward a three-course track in Bioinformatics.

Instructor: Weisman

605.721 Design and Analysis of Algorithms
In this follow-on course to 605.421 Foundations of Algorithms, design paradigms are explored in greater depth, and more advanced techniques for solving computational problems are presented. Topics include randomized algorithms, adaptive algorithms (genetic, neural networks, simulated annealing), approximate algorithms, advanced data structures, online algorithms, computational complexity classes and intractability, formal proofs of correctness, sorting networks, and parallel algorithms. Students will read research papers in the field of algorithms and will investigate the practicality and implementation issues with state-of-the-art solutions to algorithmic problems. Grading is based on problem sets, programming projects, and in-class presentations.

Prerequisites
605.421 Foundations of Algorithms or equivalent; 605.203 Discrete Mathematics or equivalent.

Instructor: Boon

605.722 Computational Complexity
Computational complexity theory is concerned with the intrinsic complexity of computational tasks, asking what can be achieved with limited computational resources. This course provides an introduction to complexity theory, emphasizing the implications of theoretic results for applications in computer science. In doing so, it comes to grips with ques-
tions such as the following: Is it easier to verify a proposed solution to a problem than it is to find a solution? Is it easier to find an approximate solution than an exact solution? Are randomized algorithms more powerful than deterministic algorithms? Are quantum computers more powerful than classical computers? In studying the progress that has been made on questions such as these, we will develop insights into the nature of computation and the implications of complexity theory for the practical development of algorithms. Specific topics include the P vs. NP problem (why is this problem so fundamental, and why is it so hard to solve?); approximation algorithms for NP-hard optimization problems; the limits of approximability; randomized algorithms, interactive proofs, and pseudorandomness; complexity and cryptography; and quantum complexity. All background in theoretical computer science is developed as needed in the course.

Prerequisites
605.421 Foundations of Algorithms or equivalent.
Instructor: Zaret

605.725 Queuing Theory with Applications to Computer Science
Queues are a ubiquitous part of everyday life; common examples are supermarket checkout stations, helpdesk call centers, manufacturing assembly lines, wireless communication networks, and multitasking computers. Queuing theory provides a rich and useful set of mathematical models for the analysis and design of service process for which there is contention for shared resources. This course explores both theory and application of fundamental and advanced models in this field. Fundamental models include single- and multiple-server Markov queues, bulk arrival and bulk service processes, and priority queues. Applications emphasize communication networks and computer operations but may include examples from transportation, manufacturing, and the service industry. Advanced topics may vary.

Prerequisites
Multivariate calculus and a graduate course in probability and statistics such as 625.403 Statistical Methods and Data Analysis or equivalent.

Course Notes
This course is the same as 625.734 Queuing Theory with Applications to Computer Science.
Instructor: Nickel

605.726 Game Theory
Game theory is a field of applied mathematics that describes and analyzes interactive decision making when two or more parties are involved. Since finding a firm mathematical footing in 1928, it has been applied to many fields, including economics, political science, foreign policy, and engineering. This course will serve both as an introduction to and a survey of applications of game theory. Therefore, after covering the mathematical foundational work with some measure of mathematical rigor, we will examine many real-world situations, both historical and current. Topics include two-person/N-person game, cooperative/non-cooperative game, static/dynamic game, combinatorial/strategic/coalitional game, and their respective examples and applications. Further attention will be given to the meaning and the computational complexity of finding of Nash equilibrium.

Prerequisites
Multivariate calculus, linear algebra and matrix theory (e.g., 625.409), and a course in probability and statistics (such as 625.403).

Course Notes
This course is the same as 625.741 Game Theory.
Instructor: Zaret

605.727 Computational Geometry
This course covers fundamental algorithms for efficiently solving geometric problems, especially ones involving 2D polygons and 3D polyhedrons. Topics include elementary geometric operations; polygon visibility, triangulation, and partitioning; computing convex hulls; Voronoi diagrams and Delaunay triangulations with applications; special polygon and polyhedron algorithms such as point containment and extreme point determination; point location in a planar graph subdivision; and robot motion planning around polygon obstacles. The course covers theory to the extent that it aids in understanding how the algorithms work. Emphasis is placed on implementation, and programming projects are an important part of the course work.

Prerequisites
Familiarity with linear algebra.
Instructor: Hansen

605.728 Quantum Computation
Polynomial time quantum algorithms, which exploit non-classical phenomena such as superposition and entanglement, have been developed for problems for which no efficient classical algorithm is known. The discovery of these fast quantum algorithms has given rise to the field of quantum computation, an emerging research area at the intersection of computer science, physics, and mathematics. This course provides an introduction to quantum computation for computer scientists. Familiarity with quantum mechanics is not a prerequisite. Instead, relevant aspects of the quantum mechanics formalism will be developed in class. The course begins with a discussion of the quantum mechanics formalism and relevant ideas from (classical) computational complexity. It then develops the idea of a quantum computer. This discussion provides the basis for a detailed examination of Shor’s polynomial time algorithm for integer factorization and Grover’s search algorithm. The course concludes with a discussion of quantum cryptography. Required work will include problem sets and a research project.

Prerequisites
Some familiarity with linear algebra and with the design and analysis of algorithms.
Instructor: Zaret
605.741 Distributed Database Systems: Cloud Computing and Data Warehouses

This course investigates the architecture, design, and implementation of massive-scale data systems. The course discusses foundational concepts of distributed database theory including design and architecture, security, integrity, query processing and optimization, transaction management, concurrency control, and fault tolerance. It then applies these concepts to both large-scale data warehouse and cloud computing systems. The course blends theory with practice, with each student developing both distributed database and cloud computing projects.

Prerequisites
605.441 Principles of Database Systems and 605.481 Principles of Enterprise Web Development or equivalent knowledge of Java and HTML. Familiarity with “big-O” concepts and notation is recommended

Course Notes
Formerly 605.741 Distributed Database Systems.

Instructor: Silberberg

Online Option Available

605.744 Information Retrieval

A multibillion-dollar industry has grown to address the problem of finding information. Commercial search engines are based on information retrieval: the efficient storage, organization, and retrieval of text. This course covers both the theory and practice of text retrieval technology. Topics include automatic index construction, formal models of retrieval, Internet search, text classification, multilingual retrieval, question answering, and related topics in NLP and computational linguistics. A practical approach is emphasized, and students will complete several programming projects to implement components of a retrieval engine. Students will also give a class presentation based on an independent project or a research topic from the IR literature.

Instructors: McNamee, Navarro

605.745 Reasoning Under Uncertainty

This course provides an introduction to current research in uncertainty management, which is one of the central research areas within artificial intelligence. The principal focus of the course is on Bayesian networks, which are at the cutting edge of this research. Bayesian networks are graphical models which, unlike traditional rule-based methods, provide techniques for reasoning under conditions of uncertainty in a consistent, efficient, and mathematically sound way. While Bayesian networks are the main topic, the course examines a number of alternative formalisms as well. Specific topics include foundations of probability theory, Bayesian networks (knowledge representation and inference algorithms), belief functions (Dempster-Shafer theory), graphical models for belief functions, and fuzzy logic. Pertinent background in probability and theoretical computer science is developed as needed in the course.

Instructor: Zaret

605.746 Machine Learning

How can machines improve with experience? How can they discover new knowledge from a variety of data sources? What computational issues must be addressed to succeed? These are questions that are addressed in this course. Topics range from determining appropriate data representation and models for learning, understanding different algorithms for knowledge and model discovery, and using sound theoretical and experimental techniques in assessing performance. Specific approaches covered include statistical techniques (e.g., k-nearest neighbor and Bayesian learning), logical techniques (e.g., decision tree and rule induction), function approximation (e.g., neural networks and kernel methods), and reinforcement learning. The topics are discussed in the context of current machine learning and data mining research. Students will participate in seminar discussions and will complete and present the results of an individual project.

Prerequisites
605.445 Artificial Intelligence is recommended but not required.

Instructor: Sheppard

Online Option Available

605.747 Evolutionary Computation

Recently, principles from the biological sciences have motivated the study of alternative computational models and approaches to problem solving. This course explores how principles from theories of evolution and natural selection can be used to construct machines that exhibit nontrivial behavior. In particular, the course covers techniques from genetic algorithms, genetic programming, and artificial life for developing software agents capable of solving problems as individuals and as members of a larger community of agents. Specific topics addressed include representation and schemata; selection, reproduction, and recombination; theoretical models of evolutionary computation; optimal allocation of trials (i.e., bandit problems); search, optimization, and machine learning; evolution of programs; population dynamics; and emergent behavior. Students will participate in seminar discussions and will complete and present the results of an individual project.

Prerequisites
605.445 Artificial Intelligence is recommended but not required.

Instructor: Sheppard

Online Option Available

605.748 Semantic Natural Language Processing

This course introduces the fundamental concepts underlying knowledge representation, semantics, and pragmatics in natural language processing. Students will gain an in-depth understanding of the techniques central to computational semantics and discourse for processing linguistic information. The course examines semantic NLP models and algorithms using both the traditional symbolic and the more recent sta-
tical approaches. The course also covers the development of modern NLP systems capable of carrying out dialogue and conversation. This course and 605.446 Natural Language Processing can be taken independently of each other.

Prerequisites
605.445 Artificial Intelligence or equivalent.

Instructor: Kumar

605.751 Computational Aspects of Molecular Structure
This course focuses on computational methods for studying protein and RNA structure, protein-protein interactions, and biological networks. Algorithms for prediction of RNA secondary structure, protein-protein interactions, and annotation of protein secondary/tertiary structure and function are studied in depth. Students will apply various computer programs and structure-visualization software to secondary and tertiary protein structure prediction, structure-structure comparison, protein domain classification, annotation of functionally important sites, and protein design. Interesting aspects of protein interaction and metabolic networks are also discussed.

Prerequisites
605.205 Molecular Biology for Computer Scientists or equivalent. 605.451 Principles of Computational Biology is recommended.

Instructors: Przytycka and Panchenko

605.754 Analysis of Gene Expression and High-Content Biological Data
The development of microarray technology, rapid sequencing, protein chips, and metabolic data has led to an explosion in the collection of “high-content” biological data. This course explores the analysis and mining of RNA expression data and high-content biological data. A survey of gene and protein arrays, laboratory information management systems, data normalization, and available tools is followed by a more in-depth treatment of differential gene expression detection, clustering techniques, pathway extraction, network model building, biomarker evaluation, and model identification. Both clinical and research data will be considered. The student will develop skills in statistical analysis and data mining, including statistical detection theory, nonlinear and multiple regression, entropy measurement, detection of hidden patterns in data, heuristic search, and learning algorithms. Applied mathematical concepts and biological principles will be introduced, and students will focus on algorithm design and software application for designing and implementing novel ways of analyzing gene, protein, and metabolic expression data. Students will complete data analysis assignments individually and in small teams.

Prerequisites
605.205 or equivalent or a prior course in bioinformatics, a course in probability and statistics, and ability to program in a high-level language.

Course Notes
There are no exams, but programming assignments are intensive. Students in the MS Bioinformatics program may take both this course and 410.671 Microarrays and Analysis, as the content is largely mutually exclusive.

Instructor: Boon

605.755 Systems Biology
During the last decade, systems biology has emerged as an effective tool for investigation of complex biological problems, placing emphasis on the analysis of large-scale data sets and quantitative treatment of experimental results. In this course, students will explore recent advances in systems biology analysis of intracellular processes. Examples of modeling and experimental studies of metabolic, genetic, signal transduction, and cell cycle regulation networks will be studied in detail. The classes will alternate between consideration of network-driven and network element (gene, metabolite, or protein)-driven approaches. Students will learn to use Boolean, differential equations, and stochastic methods of analysis and will become acquainted with several powerful experimental techniques, including basics of microfabrication and microfluidics. For their course projects, students will develop models of a signal transduction or metabolic pathway.

Prerequisites
Courses in molecular biology (605.205 Molecular Biology for Computer Scientists or 410.602 Molecular Biology) and differential equations.

Instructor: Levchenko

605.759 Independent Project in Bioinformatics
This course is for students who would like to carry out a significant project in bioinformatics as part of their graduate program. The course may be used to conduct minor research, an in-depth literature survey, or a software implementation related to recent developments in the field. Students who enroll in this course are encouraged to attend at least one industry conference in bioinformatics that is related to their area of study. To enroll in this course, the student must be within two courses of degree completion and must obtain the approval and support of a sponsoring faculty member.

Course Notes
A student may not receive credit for both 605.759 and 605.802 Independent Study in Computer Science II.

Instructor: Staff

605.767 Applied Computer Graphics
This course examines advanced rendering topics in computer graphics. The course focuses on the mathematics and theory behind 3D graphics rendering. Topics include 3D surface representations including fractal geometry methods; visible surface detection and hidden surface removal; and surface rendering methods with discussion of lighting models, color theory, texturing, and ray tracing. Laboratory exercises provide practical application of these concepts. The course also
includes a survey of graphics rendering applications (animation, modeling and simulation, and realistic rendering) and software. Students perform laboratory exercises using the C++ programming language.

Prerequisites
605.467 Computer Graphics or familiarity with three-dimensional viewing and modeling transformations.

Instructor: Nesbitt

605.771 Wired and Wireless Local and Metropolitan Area Networks
This course provides a detailed examination of wired and wireless Local and Metropolitan Area Network technologies, protocols, and the methods used for implementing LAN- and MAN-based enterprise intranets. The structure and operation of the IEEE 802 media access control (MAC) and physical layer protocols are examined in detail. The 802.2 logical link control, 802.3/Ethernet, 802.4 token bus, and the 802.5 token ring protocols are analyzed, and the construction of LAN-based enterprise intranets is examined through a detailed analysis of bridging, routing, and switching techniques. High-speed LAN technologies are discussed through an examination of FDDI, Fast Ethernet, 100VG AnyLAN, ATM LAN Emulation (LANE), and Fibre Channel protocols, along with the new standards for Gigabit and 10 Gigabit Ethernet. In addition, the 802.6 DQDB and 802.17 Resilient Packet Ring MAN protocols are discussed. Finally, the new and emerging wireless LAN and MAN standards are examined. The 802.11 (WiFi) wireless LAN and 802.15 (Bluetooth) wireless PAN standards are discussed in detail along with the emerging 802.16 (WiMAX) wireless MAN standard. Topics include Manchester and Differential Manchester encoding techniques; bus, star, and ring topologies; optical fiber, coaxial cable, and UTP media; baseband, broadband, and carrier-band bus networks; hubs, switched LANs and full duplex LANs; VLANs and prioritization techniques; transparent and source routing bridge algorithms; packet bursting and carrier extension schemes; wireless spread spectrum and frequency hopping transmission techniques; wireless collision avoidance media access control; and security schemes. Students may use the network lab to configure LAN switches and Cisco routers, as well as to observe the interconnection of LAN networks.

Prerequisites
605.471 Principles of Data Communications Networks.

Instructors: Hsu, Nieporent

605.772 Network Management
Network management (NM) refers to the activities, methods, operational procedures, tools, communications interfaces, protocols, and human resources that pertain to the operation, administration, maintenance, and provisioning of communications networks and plan for their growth and evolution. The course will cover network management standards, technologies, industry best practices, and case studies. The study areas are broadly organized under the functional areas of fault management, configuration management, accounting management, performance management, and security management. Security management includes identity management, authentication, authorization, access control, intrusion prevention, detection, and correction. Network managers set, monitor, and maintain certain performance metrics pertaining to the functional areas to ensure high performance levels and quality of service (QoS) to the users. Network management includes network architecture planning, design, and operations as well as IT management. This course covers major Internet and telecommunications standards for network management as they apply to voice, data, and video services: SNMP/v1, SNMP/v2, SNMP/v3, RMON, and TMN. Other standards covered include 3GPP/IMS, Cable, DSL, RSVP, TIA-1039, DiffServ, and IntServ. This course will also examine areas in network management that can be automated.

Prerequisites

Instructor: Krishnan

605.775 Optical Networking Technology
The Internet has hundreds of millions of users, is growing rapidly, and continues to evolve to accommodate an increasing number of voice, data, video, and imagery applications with diverse service requirements. Internet Protocol (IP) is the primary unifying protocol converging these applications and services over the Internet. The Internet’s evolution has been accompanied by exponentially growing traffic volume on the network infrastructure. Optical networks are ideally suited to carry such large volumes of traffic, and the next generation of optical networks will be optimized for delivery of IP services while providing capacity in the range of terabits per second in a scalable and flexible way to support services such as voice over IP (VoIP) and IP television (IPTV). This course provides an in-depth understanding of existing and emerging optical network technologies. Specific topics covered include basics of fiber optic communications, SONET, DWDM, optical Ethernet, FTTH, FTTB, optical wavelength switching, IP over optical networks, MPLS, and GMPLS. Additional topics that may be discussed include optical network standards, network control and management, static and dynamic service provisioning, optical network design, and future directions.

Prerequisites
605.473 High-Speed Networking Technologies or permission of the instructor.

Instructor: Krishnan

605.776 Fourth-Generation Wireless Communications: WiMAX and LTE
This course compares the WiMAX and LTE fourth-generation (4G) technologies and their performance. An overview of the IEEE 802.16 standards (802.16d/e/j/m/n/p) and WiMAX
The Internet has been growing exponentially and continues to evolve to accommodate an increasingly large number of applications with diverse service requirements. A remarkable aspect of this evolution is the convergence of real-time communications services with traditional data communications services over the Internet. In particular, Internet telephony, or voice over IP, is one of the most promising services currently being deployed. While there are many benefits to voice over IP, such as cost effectiveness and enhanced features, there exist a number of barriers to the widespread deployment of Internet telephony. The purpose of this course is to provide in-depth understanding of the concept and operation of voice over IP and discuss issues and strategies to address the issues. In this course, students will gain understanding of how to adapt an IP packet network, which is basically designed for data, to provide wide-area voice communications. Topics include telephony fundamentals, voice over IP concepts, adapting IP networks to support voice, H.323 and SIP signaling protocols, QoS issues in IP networks, IETF standards, and network management.

**Prerequisites**

605.477 Internetworking with TCP/IP I or 605.473 High-Speed Networking Technologies, or significant Internet technology-related work experience.

**Instructor:** Krishman

**Online Option Available**

### 605.782 Web Application Development with Java

This project-oriented course will enable the students to use various techniques for building browser-based applications for dynamically generated websites, e-commerce, web-enabled enterprise computing, and other applications that require web access to server-based resources. Particular attention will be paid to methods for making web-based applications efficient, maintainable, and flexible. The course will use at least
two sets of tools: servlets/JSP and a higher-level Java-based framework such as JSF 2.0. Major topics will include handling HTTP request information, generating HTTP response data, tracking sessions, designing custom tag libraries or components, page templating, asynchronous page updates with Ajax, and separating content from presentation through use of the MVC architecture. Additional topics may include HTML5, database access techniques for web apps, web app security, and dependency injection in web apps (e.g., with the Spring framework).

**Prerequisites**
605.481 Principles of Enterprise Web Development or equivalent Java experience.

**Course Notes**
Formerly 605.782 Web Application Development with Servlets and JavaServer Pages (JSP).

**Instructors:** Chaikin, Chittargi, Hall

Online Option Available

**605.784 Enterprise Computing with Java**
This course covers enterprise computing technologies using Java Enterprise Edition (Java EE). The course describes how to build multitier distributed applications, specifically addressing web access, business logic, data access, and applications supporting enterprise service technologies. For the web access tier, the focus will be on development using servlets and JSP with an emphasis on integrating the web tier with enterprise applications. For the business logic tier, session beans for synchronous business processing and message-driven beans and timers for asynchronous business processing will be described. The data access tier discussion will focus on Java database connectivity (JDBC), data access patterns, and the Java Persistence API. Finally, enterprise services will be discussed, including the Java Naming and Directory Interface (JNDI), the Java message service (JMS), remote method invocation (RMI), Java Transaction API (JTA), and Java EE security. Students will build applications using the technologies presented.

**Prerequisites**
605.481 Principles of Enterprise Web Development or equivalent.

**Instructors:** Felikson, Shyamsunder, Stafford

Online Option Available

**605.785 Web Services with SOAP and REST: Frameworks, Processes, and Applications**
Web services is a technology, process, and software paradigm to extend the web from an infrastructure that provides services for humans to one that supports business integration over the web. This course presents concepts, features, and architectural models of web services from three perspectives: framework, process, and applications. Students will study three emerging standard protocols: Simple Object Access Protocol (SOAP); Web Services Description Language (WSDL); and Universal Description, Discovery, and Integration (UDDI). In contrast, Representational State Transfer (REST) is an architectural style for designing networked applications and exposing web services. REST delivers simplicity and true interoperability and is an alternative to complex mechanism such as CORBA, RPC, or SOAP-based web services and allows using simple HTTP to make calls between machines. The course will explain the REST principles and show how to use the Java standards for developing applications using RESTful API. Students will learn the benefits of and the technical architecture for using REST in applications, including how to design, build, and test RESTful services using Java and JAX-RS. This includes the role of key technologies such as HTTP, Extensible Markup Language (XML), and JavaScript Object Notation (JSON). Students also learn how to consume RESTful services in applications, including the role of JavaScript and Ajax, and how the RESTful approach differs from the SOAP-based approach, while comparing and contrasting the two techniques. Finally, the course will review other web services specifications and standards, and it will describe the use of web services to resolve business applications integration issues. WS-I Basic Profile and other guidance documents and recommended practices will be discussed in the context of achieving high levels of web services interoperability.

**Prerequisites**
605.444 XML Design Paradigms or equivalent XML and Java programming experience; knowledge of the J2EE platform and programming model is recommended.

**Instructor:** Felikson

Online Option Available

**605.786 Enterprise System Design and Implementation**
This course explores enterprise architectures for the development of scalable distributed systems. Effective patterns for distributed data access, MVC-based web tiers, and business logic components are explored as students build complex applications. Factors such as caching and clustering that enable distributed systems to scale to handle potentially thousands of users are a primary focus. In addition, creating a reusable blueprint for an enterprise architecture will be discussed. Applications developed utilizing these concepts are selected from current research topics in information retrieval, data visualization, and machine learning.

**Prerequisites**
605.784 Enterprise Computing with Java. 605.707 Design Patterns or equivalent experience is recommended.

**Instructors:** M. Cherry and P. Cherry

**605.787 Rich Internet Applications with Ajax**
Using a web browser to access online resources is convenient because it provides universal access from any computer on any operating system in any location. Unfortunately, it often results in a poor user experience because HTML is a weak and noninteractive display language and HTTP is a weak and inefficient protocol. Full-fledged browser-embedded pro-
grams (e.g., ActiveX components, Java applets) have not succeeded in penetrating the market adequately, so a new class of applications has grown up that uses only the capabilities already available in most browsers. These applications were first popularized by Google but have since exploded in popularity throughout the developer community. The techniques to implement them were based on a group of technologies collectively known as Ajax, and the resultant applications were richer than the relatively static pure-HTML-based web applications that preceded them. These applications have become known as Ajax applications, rich internet applications, or Web 2.0 applications. This course will examine techniques to develop and deploy Ajax applications. We will look at the underlying techniques, then explore client-side tools (e.g., jQuery), server-side tools (e.g., JSON-RPC), and hybrid tools (e.g., the Google Web Toolkit) to simplify the development process. As we delve into several popular client and server-side libraries, we will be examining and paying attention to issues of usability, efficiency, security, and portability.

**Prerequisites**

605.782 Web Application Development with Java or equivalent servlet and JSP experience.

**Instructors:** Chaikin, Hall, Shyamsunder

**Online Option Available**

**605.788  Big Data Processing Using Hadoop**

Organizations today are generating massive amounts of data that are too large and too unwieldy to fit in relational databases. So, organizations and enterprises are turning to massively parallel computing solutions such as Hadoop for help. The Apache Hadoop platform, with Hadoop Distributed File System (HDFS) and MapReduce (M/R) framework at its core, allows for distributed processing of large data sets across clusters of computers using the map and reduce programming model. It is designed to scale up from a single server to thousands of machines, offering local computation and storage. The Hadoop ecosystem is sizable in nature and includes many subprojects such as Hive and Pig for big data analytics, HBase for real-time access to big data, Zookeeper for distributed transaction process management, and Oozie for workflow. This course breaks down the walls of complexity of distributed processing of big data by providing a practical approach to developing applications on top of the Hadoop platform. By completing this course, students will gain an in-depth understanding of how MapReduce and Distributed File Systems work. In addition, they will be able to author Hadoop-based MapReduce applications in Java and also leverage Hadoop subprojects to build powerful data processing applications.

**Prerequisites**

605.481 Principles of Enterprise Web Development or equivalent Java experience.

**Course Notes:** This course may be counted toward a three-course track in Databases and Knowledge Management.

**Instructors:** D. May, Shyamsunder

**605.801  Independent Study in Computer Science I**

This course permits graduate students in computer science to work with a faculty mentor to explore a topic in depth or conduct research in selected areas. Requirements for completion include submission of a significant paper or project.

**Prerequisites**

Seven computer science graduate courses including the foundation courses, three concentration area courses, and two courses numbered 605.7xx, or admission to the advanced certificate for post-master's study. Students must also have permission of a faculty mentor, the student's academic advisor, and the program chair.

**605.802  Independent Study in Computer Science II**

Students wishing to take a second independent study in computer science should sign up for this course.

**Prerequisites**

605.801 Independent Study in Computer Science I and permission of a faculty mentor, the student's academic advisor, and the program chair. A student may not receive credit for both 605.759 Independent Project in Bioinformatics and 605.802.

**600.647  Advanced Topics in Wireless Networks**

This class will survey current research in wireless communication networks. These types of networks have been growing exponentially in the past several years and include a host of different network types: ad hoc, cell phone, access point, sensor, etc. The class will build understanding of all layers of wireless networking and the interactions between them (including: physical, data link, medium access control, routing, transport, and application). The topics of security, energy efficiency, mobility, scalability, and their unique characteristics in wireless networks will be discussed.

**Prerequisites**

600.344/444 and 600.363/463, or permission of the instructor.

**Instructor:** Mishra
Electrical and Computer Engineering

Electrical and computer engineering is concerned with the use of electrical phenomena for communication, computation, information transformation, power generation and transmission, measurement, and control. Within these broad categories exist application areas affecting nearly every facet of society. Electrical and computer engineering draws upon mathematics and the basic sciences of physics, chemistry, and materials in developing the technology leading to new devices, and the techniques for describing and designing the processes that take place in electrical systems. The strength of the EP Electrical and Computer Engineering (ECE) program lies in the active involvement of the faculty in applied research and development, and the faculty's commitment to fostering students' understanding of the theory and practice of the discipline.

Within the Whiting School of Engineering, two master's degree programs are offered in Electrical and Computer Engineering, the Master of Science and the Master of Science in Engineering.

The Master of Science (MS) degree is offered through the EP program and is administered by a program committee. The MS program course requirements are described in detail below. It provides graduate education in both the fundamentals of various branches of electrical and computer engineering and in the more specific aspects of current technologies of clear importance. The aim is to serve working engineers primarily; nearly all students participate part time. Courses are offered during evening hours at the Applied Physics Laboratory, the Dorsey Center, and the Montgomery County Campus, or via online delivery. The faculty is drawn from the technical staff of the Applied Physics Laboratory, from government and local industry, and from the full-time faculty of JHU's Department of Electrical and Computer Engineering.

The areas of interest within the MS program span a broad spectrum of specialties. Courses are offered within the general areas of telecommunications and networking, computer engineering, RF and microwave engineering, optics and photonics, electronics and the solid state, signal processing, and systems and control.

Students who are interested may, with program approval, plan and complete a thesis project after all other requirements for the master's degree have been completed. Such students work with an advisor to conduct independent applied research and development in the field of electrical and computer engineering.

The Master of Science in Engineering (MSE) degree is offered and administered by the Department of Electrical and Computer Engineering. Courses are offered during the day and late afternoon hours, mainly at the Homewood campus. Admission and graduation requirements are similar to those of the MS program, and interactions are possible. The MSE program provides graduate education in the context of a full-time academic department. The aim is to provide master's level work in closer contact with full-time faculty and PhD candidates than is the case in the MS program. The faculty is drawn primarily from the Department of Electrical and Computer Engineering but also from the technical staff of the Applied Physics Laboratory. Additional information concerning the MSE program, including the catalog and admission materials, may be obtained from the Department of Electrical and Computer Engineering at Homewood.

Program Committee

Brian K. Jennison, Program Chair
Principal Professional Staff
Applied Physics Laboratory

Clinton L. Edwards, Program Vice Chair
Senior Professional Staff
Applied Physics Laboratory

James J. Costabile
Vice President
Data Design Corporation

Andrew D. Goldfinger
Principal Professional Staff
Applied Physics Laboratory

Jeffrey G. Houser
Electronics Engineer
U.S. Army Research Laboratory

Daniel G. Jablonski
Principal Professional Staff
Applied Physics Laboratory

Jin Ung Kang
Professor, Electrical and Computer Engineering
Whiting School of Engineering

John E. Penn
Electronics Engineer
U.S. Army Research Laboratory

Raymond M. Sova
Principal Professional Staff
Applied Physics Laboratory

Douglas S. Wenstrand
Principal Professional Staff
Applied Physics Laboratory

Admission Requirements

Applicants must meet the general requirements for admission to graduate programs outlined in this catalog. In addition, applicants are expected to have (1) majored in an Accreditation Board for Engineering and Technology (ABET)–accred-
and Electrical and Computer Engineering allows students, working with advisors, to structure programs that meet their professional development needs.

Electrical and Computer Engineering students who select the Telecommunications and Networking area of concentration must complete the standard program requirements with the following additional requirements. Of the minimum of seven Electrical and Computer Engineering courses, at least five must be Telecommunications and Networking courses. Of the maximum of three electives, at least two must be from the Computer Science Telecommunications and Networking set of courses.

**Graduate Courses for the Telecommunications and Networking Concentration**

**Computer Science Courses**

- 605.471 Principles of Data Communications Networks
- 605.472 Computer Network Architectures and Protocols
- 605.473 High-Speed Networking Technologies
- 605.474 Network Programming
- 605.475 Protocol Design and Simulation
- 605.477 Internetworking with TCP/IP I
- 605.478 Cellular Communications Systems
- 605.771 Wired and Wireless Local and Metropolitan Area Networks
- 605.772 Network Management
- 605.775 Optical Networking Technology
- 605.776 Fourth-Generation Wireless Communications: WiMAX and LTE
- 605.777 Internetworking with TCP/IP II
- 605.778 Voice Over IP
- 695.422 Web Security
- 695.701 Cryptology
- 695.721 Network Security

**Electrical and Computer Engineering Courses**

- 525.408 Digital Telephony
- 525.414 Probability and Stochastic Processes for Engineers
- 525.416 Communication Systems Engineering
- 525.418 Antenna Systems
- 525.420 Electromagnetic Transmission Systems
- 525.438 Introduction to Wireless Technology
- 525.440 Satellite Communications Systems
- 525.441 Computer and Data Communication Networks I
- 525.707 Error Control Coding
- 525.708 Iterative Methods in Communications Systems
- 525.722 Wireless and Mobile Cellular Communications
- 525.723 Computer and Data Communication Networks II

**Telecommunications and Networking Area of Concentration**

The field of telecommunications and networking is one of great importance to our society. As a technical discipline, it draws from the more traditional fields of computer science and electrical engineering. Although the EP program does not offer a separate master’s degree in telecommunications and networking, students may pursue a concentration in this area as a degree candidate in Electrical and Computer Engineering. The wide variety of courses from both Computer Science and Electrical and Computer Engineering allows students,
Electrical and Computer Engineering

Three additional courses must be selected from the lists below. The three additional courses needed to complete the degree may be any courses approved by the advisor, selected so as to fulfill the general requirements for the MS degree.

Applied Physics Courses
- 615.751 Modern Optics
- 615.758 Modern Topics in Applied Optics
- 615.778 Computer Optical Design
- 615.780 Optical Detectors and Applications
- 615.781 Quantum Information Processing
- 615.782 Optics and MATLAB

Electrical and Computer Engineering Courses
- 525.413 Fourier Techniques in Optics
- 525.425 Laser Fundamentals
- 525.436 Optics and Photonics Laboratory
- 525.491 Fundamentals of Photonics
- 525.753 Laser Systems and Applications
- 525.756 Optical Propagation, Sensing, and Backgrounds
- 525.772 Fiber-Optic Communication Systems
- 525.792 Electro-Optical Systems
- 525.796 Introduction to High-Speed Electronics and Optoelectronics
- 525.797 Advanced Optics and Photonics Laboratory

Note: 525.801 and 525.802 Special Project courses can also be used to allow students to pursue specialized interests in optics.

Applied Biomedical Engineering Course
- 585.634 Biophotonics

Advanced Certificate for Post-Master’s Study
This certificate is awarded to students who complete six graduate-level courses beyond the master’s degree in an electrical and computer engineering discipline. The program is intended to add depth and/or breadth in the discipline of the student’s master’s degree, or a closely related one. All grades for the six courses must be B or above.

After the review of student’s academic credentials by the admission committee and admittance to the Advanced Certificate for Post-Master’s Study program, each student is assigned an advisor with whom he or she jointly designs a program tailored to individual educational goals.

Students must complete the Advanced Certificate for Post-Master’s Study within three years of the first enrollment in the program.

Electrical and Computer Engineering—Online
There are numerous courses in the Electrical and Computer Engineering program offered in a fully online format, and more courses are continually being developed. This increases the flexibility of course offerings for students wishing to pursue studies in either the face-to-face or online format, or a combination of both.
Online course content is identical to that in the face-to-face offerings but available in a paced, asynchronous mode over the Internet. Recorded lectures with associated multi-media content are augmented with online discussions and weekly synchronous office hours. Prospective and current students should consult the EP website for the current online course offerings, course schedules, and procedures for online programs.

For convenient reference, the course offerings of the Master of Science in Electrical and Computer Engineering program are listed below in technology groupings. Although most students choose from within one or two groupings, no particular restrictions apply.

I. Telecommunications and Networking

- 525.408 Digital Telephony
- 525.414 Probability and Stochastic Processes for Engineers
- 525.416 Communication Systems Engineering
- 525.418 Antenna Systems
- 525.420 Electromagnetic Transmission Systems
- 525.438 Introduction to Wireless Technology
- 525.440 Satellite Communications Systems
- 525.441 Computer and Data Communication Networks I
- 525.707 Error Control Coding
- 525.708 Iterative Methods in Communications Systems
- 525.722 Wireless and Mobile Cellular Communications
- 525.723 Computer and Data Communication Networks II
- 525.735 MIMO Wireless Communications
- 525.736 Smart Antennas for Wireless Communications
- 525.738 Advanced Antenna Systems
- 525.747 Speech Processing
- 525.751 Software Radio for Wireless Communications
- 525.754 Wireless Communication Circuits I
- 525.759 Image Compression, Packet Video, and Video Processing
- 525.761 Wireless and Wireline Network Integration
- 525.768 Wireless Networks
- 525.771 Propagation of Radio Waves in the Atmosphere
- 525.772 Fiber-Optic Communication Systems
- 525.776 Information Theory
- 525.783 Spread-Spectrum Communications
- 525.789 Digital Satellite Communications
- 525.791 Microwave Communications Laboratory
- 525.793 Advanced Communication Systems

II. Computer Engineering

- 525.410 Microprocessors for Robotic Systems

III. RF and Microwave Engineering

- 525.405 Intermediate Electromagnetics
- 525.418 Antenna Systems
- 525.420 Electromagnetic Transmission Systems
- 525.423 Principles of Microwave Circuits
- 525.448 Introduction to Radar Systems
- 525.484 Microwave Systems and Components
- 525.736 Smart Antennas for Wireless Communications
- 525.738 Advanced Antenna Systems
- 525.754 Wireless Communication Circuits
- 525.771 Propagation of Radio Waves in the Atmosphere
- 525.774 RF and Microwave Circuits I
- 525.775 RF and Microwave Circuits II
- 525.779 RF Integrated Circuits
- 525.787 Microwave Monolithic Integrated Circuit (MMIC) Design
- 525.788 Power Microwave Monolithic Integrated Circuit (MMIC) Design
- 525.791 Microwave Communications Laboratory

IV. Optics and Photonics

- 525.413 Fourier Techniques in Optics
- 525.425 Laser Fundamentals
- 525.436 Optics and Photonics Laboratory
- 525.491 Fundamentals of Photonics
- 525.753 Laser Systems and Applications
- 525.756 Optical Propagation, Sensing, and Backgrounds
- 525.772 Fiber-Optic Communication Systems
- 525.792 Electro-Optical Systems
- 525.796 Introduction to High-Speed Electronics and Optoelectronics
- 525.797 Advanced Optics and Photonics Laboratory
V. Electronics and the Solid State
525.406 Electronic Materials
525.407 Introduction to Electronic Packaging
525.421 Introduction to Electronics and the Solid State I
525.422 Introduction to Electronics and the Solid State II
525.424 Analog Electronic Circuit Design I
525.428 Introduction to Digital CMOS VLSI
525.432 Analog Electronic Circuit Design II
525.451 Introduction to Electric Power Systems
525.713 Analog Integrated Circuit Design
525.725 Power Electronics

VI. Signal Processing
525.419 Introduction to Digital Image and Video Processing
525.427 Digital Signal Processing
525.430 Digital Signal Processing Lab
525.431 Adaptive Signal Processing
525.443 Real-Time Computer Vision
525.446 DSP Hardware Lab
525.448 Introduction to Radar Systems
525.718 Multirate Signal Processing

VII. Systems and Control
525.409 Continuous Control Systems
525.414 Probability and Stochastic Processes for Engineers
525.445 Modern Navigation Systems
525.466 Linear System Theory
525.744 Passive Emitter Geo-Location
525.763 Applied Nonlinear Systems
525.770 Intelligent Algorithms
525.777 Control System Design Methods
615.441 Mathematical Methods for Physics and Engineering
625.743 Stochastic Optimization and Control

Course Descriptions
Please refer to the Course Schedule published each semester for exact dates, times, locations, fees, and instructors.

520.772 Advanced Integrated Circuits
Study of devices, circuits, and design methodology for analog computing systems, both MOS and bipolar. Students will use CAD tools to design and test circuits fabricated through the MOSIS service with special emphasis on bio-inspired integrated sensors and sensory systems and on micropower integrated circuits for biomedical devices and instrumentation.
Instructors: Andreou, Etienne-Cummings

525.201 Circuits, Devices, and Fields
This course is intended to prepare students lacking an appropriate background for graduate study in electrical and computer engineering. Fundamental mathematical concepts including calculus, differential equations, and linear algebra are reviewed. Circuit theory for linear and nonlinear devices and components is covered. An introduction to electricity and magnetism is presented along with basic wave propagation theory. Finally, Boolean algebra is studied with applications to digital circuit design and analysis. The course does not count toward the Master of Science in Electrical and Computer Engineering degree.
Course Notes
Not for graduate credit.
Instructor: Staff
Online Option Available

525.202 Signals and Systems
This course is intended to prepare students lacking an appropriate background for graduate study in electrical and computer engineering. Signal and system representations and analysis tools in both continuous time and discrete time are covered. Linear time-invariant systems are defined and analyzed. The Fourier transform, the Laplace transform, and the z-transform are treated along with the sampling theorem. Finally, fundamental concepts in probability, statistics, and random processes are considered. The course does not count toward the Master of Science in Electrical and Computer Engineering degree.
Course Notes
Not for graduate credit.
Instructors: Edwards, Jennison
Online Option Available

525.405 Intermediate Electromagnetics
This course provides a background in engineering electromagnetics required for more advanced courses in the field. Topics include vector calculus, Poisson's and Laplace's equations, Vector potentials, Green's functions, magnetostatics, magnetic and dielectric materials, Maxwell's equations, plane wave propagation and polarization, reflection and refraction at a plane boundary, frequency-dependent susceptibility functions, transmission lines, waveguides, and simple antennas. Practical examples are used throughout the course.
Instructors: Thomas, Weiss
Online Option Available
525.406  Electronic Materials
Materials and the interfaces between them are the key elements in determining the functioning of electronic devices and systems. This course develops the fundamental parameters of the basic solid material types and their relationships to electrical, thermal, mechanical, and optical properties. The application of these materials to the design and fabrication of electronic components is described, including integrated circuits, passive components, and electronic boards, modules, and systems.

Prerequisites
An undergraduate degree in engineering, physics, or materials science; familiarity with materials structures and electronic devices.

Instructor: Charles

525.407  Introduction to Electronic Packaging
Topics include fundamentals of electronic packaging engineering and basic concepts in thermal, mechanical, electrical, and environmental management of modern electronic systems. Emphasis is on high-frequency (and high-speed) package performance and its achievement through the use of advanced analytical tools, proper materials selection, and efficient computer-aided design. Packaging topics include die and lead attachment, substrates, hybrids, surface-mount technology, chip and board environmental protection, connectors, harnesses, and printed and embedded wiring boards.

Prerequisites
An undergraduate degree in a scientific or engineering area, including familiarity with computer-aided design and engineering analysis methods for electronic circuits and systems.

Instructor: Charles

525.408  Digital Telephony
This course examines communication techniques for the transmission in voice of various channels. Topics include characteristics of speech and voice digitization; bandwidth minimization and voice compression; digital modulation and standards; transmission via fiber, terrestrial microwave, and satellite channels; cellular telephone architectures and networks; and digital switching architectures and networks.

Prerequisites
Either an undergraduate degree in electrical engineering or 525.416 Communications Systems Engineering, or consent of the instructor.

Instructors: Blodgett, Carmody

525.409  Continuous Control Systems
This course examines classical methods of analysis and design of continuous control systems. Topics include system representation by linear time invariant ordinary differential equations, performance measures, sensitivity, stability, root locus, frequency domain techniques, and design methods. Several practical examples are considered. MATLAB is used as a computational tool.

Prerequisites
Matrix theory and linear differential equations.

Instructor: Palumbo

525.410  Microprocessors for Robotic Systems
This course examines microprocessors as an integral part of robotic systems. Techniques required for successful incorporation of embedded microprocessor technology are studied and applied to robotic systems. Students will use hardware in a laboratory setting and will develop software that uses features of the microprocessor at a low level to accomplish the real-time performance necessary in robotic applications. Topics will include microprocessor selection, real-time constraints, sensor interfacing, actuator control, and system design considerations.

Prerequisites
Experience with C programming and a course in digital systems or computer architecture.

Instructors: Sawyer, Golden

525.412  Computer Architecture
This course focuses on digital hardware design for all major components of a modern, reduced-instruction-set computer. Topics covered include instruction set architecture; addressing modes; register-transfer notation; control circuitry; pipelining with hazard control; circuits to support interrupts and other exceptions; microprogramming; computer addition and subtraction circuits using unsigned, two’s-complement, and excess notation; circuits to support multiplication using Robertson’s and Booth’s algorithms; circuits for implementing restoring and non-restoring division; square-root circuits; floating-point arithmetic notation and circuits; memory and cache memory systems; segmentation and paging; input/output interfaces; interrupt processing; direct memory access; and several common peripheral devices, including analog-to-digital and digital-to-analog converters.

Prerequisites
An undergraduate course in digital design.

Instructor: Beser

525.413  Fourier Techniques in Optics
In this course, the study of optics is presented from a perspective that uses the electrical engineer’s background in Fourier analysis and linear systems theory. Topics include scalar diffraction theory, Fourier transforming and imaging properties of lenses, spatial frequency analysis of optical systems, spatial filtering and information processing, and holography. The class discusses applications of these concepts in non-destructive evaluation of materials and structures, remote sensing, and medical imaging.

Prerequisites
An undergraduate background in Fourier analysis and linear systems theory.

Instructor: Young
525.414 Probability and Stochastic Processes for Engineers

This course provides a foundation in the theory and applications of probability and stochastic processes and an understanding of the mathematical techniques relating to random processes in the areas of signal processing, detection, estimation, and communication. Topics include the axioms of probability, random variables, and distribution functions; functions and sequences of random variables; stochastic processes; and representations of random processes.

Prerequisite
An undergraduate degree in electrical engineering.

Instructors: Fry, R. Lee, Murphy, Ambrose

525.415 Embedded Microprocessor Systems

This course applies microprocessors as an integral element of system design. Techniques required for successful incorporation of microprocessor technology are studied and used. Hardware and software design considerations that affect product reliability, performance, and flexibility are covered. Students use hardware to gain familiarity with machine and assembly language for software generation, interfacing to a microprocessor at the hardware level, and emulation to check out system performance. Topics include security in embedded systems, case studies in system failures, embedded processors in the space environment, communications protocols, hardware/software system tradeoffs, and SoC/FPGA designs. The course is based on the ARM architecture, and the student will do a series of development and interfacing labs.

Prerequisites
Some experience in designing and building digital electronic systems, some familiarity with C programming, and a course in digital systems.

Instructor: Stakem

525.416 Communication Systems Engineering

In this course, students receive an introduction to the principles of communication systems engineering. Students examine analog and digital communication including linear (AM, DSB, SSB) and exponential (PM, FM) modulation, sampling, noise and filtering effects, quantization effects, detection error probabilities, and coherent and noncoherent communication techniques.

Prerequisites
A working knowledge of Fourier transforms, linear systems, and probability theory.

Instructors: Alexander, Costabile, R. Lee, Marble

525.418 Antenna Systems

This course introduces and explains fundamental antenna concepts for both antennas and antenna arrays. Electromagnetic theory is reviewed and applied to antenna elements such as dipoles, loops, and aperture antennas, as well as antenna arrays. Antenna analysis is presented from a circuit theory point of view to highlight concepts such as reciprocity and the implications for transmit and receive radiation patterns. The importance of two-dimensional Fourier transforms is explained and applied to aperture antennas. Basic array constraints are examined through case studies of uniform, binomial, and general amplitude distributions. The concept of beam squint is explained through examination of constant-phase versus constant-time phase shifters. The Rotman lens is discussed as an example of a common beamformer. The class concludes with an explanation of antenna measurements.

Prerequisite
525.405 Intermediate Electromagnetics or equivalent.

Instructor: Weiss

525.419 Introduction to Digital Image and Video Processing

This course provides an introduction to the basic concepts and techniques used in digital image and video processing. Two-dimensional sampling and quantization are studied, and the human visual system is reviewed. Edge detection and feature extraction algorithms are introduced for dimensionality reduction and feature classification. High-pass and bandpass spatial filters are studied for use in image enhancement. Applications are discussed in frame interpolation, filtering, coding, noise suppression, and video compression. Some attention will be given to object recognition and classification, texture analysis in remote sensing, and stereo machine vision.

Prerequisite
525.427 Digital Signal Processing.

Instructor: Nasrabadi

525.420 Electromagnetic Transmission Systems

This course examines transmission systems used to control the propagation of electromagnetic traveling waves with principal focus emphasizing microwave and millimeter-wave applications. The course reviews standard transmission line systems together with Maxwell’s equations and uses them to establish basic system concepts such as reflection coefficient, characteristic impedance, input impedance, impedance matching, and standing wave ratio. Specific structures are analyzed and described in terms of these basic concepts, including coaxial, rectangular, and circular waveguides, surface waveguides, striplines, microstrips, coplanar waveguides, slotlines, and finlines. Actual transmission circuits are characterized using the concepts and analytical tools developed.

Prerequisites
Students must have knowledge of material covered in 525.201 and 525.202 or taken a course on intermediate electromagnetics equivalent to 525.405.

Instructor: Sequeira
525.421  Introduction to Electronics and the Solid State I
Fundamentals of solid-state and device physics are presented. Topics in solid-state physics include crystal structure, lattice vibrations, dielectric and magnetic properties, band theory, and transport phenomena. Concepts in quantum and statistical mechanics are also included. Basic semiconductor device operation is described with emphasis on the p-n junction.
Prerequisites
An undergraduate degree in electrical engineering or the equivalent.
Instructor: Charles

525.422  Introduction to Electronics and the Solid State II
This course reviews the fundamentals of device physics and electronics. Topics in device electronics include bipolar and MOS transistors, Schottky barriers, transferred electron and tunnel devices, semiconductor lasers, and solar cells. Concepts in device structure, modeling, and performance are described.
Prerequisites
525.421 Introduction to Electronics and the Solid State I or approval of the instructor.
Instructor: Charles

525.423  Principles of Microwave Circuits
This course addresses foundational microwave circuit concepts and engineering fundamentals. Topics include electromagnetics leading to wave propagation and generation, the transmission line, and impedance/admittance transformation and matching. Mapping and transformation are presented in the development of the Smith Chart. The Smith Chart is used to perform passive microwave circuit design. Microwave networks and s-matrix are presented; Mason’s rules is introduced. Circuits are physically designed using microstrip concepts, taking into consideration materials properties, connectors, and other components.
Instructor: Abita

525.424  Analog Electronic Circuit Design I
This course examines the use of passive and active components to perform practical electronic functions. Simple circuits are designed and evaluated emphasizing the characteristics and tolerances of actual components. Devices studied include diodes and bipolar and field effect transistors. Circuit designs are studied in relation to the device characteristics, including small signal amplifiers and oscillators, and linear power supply and amplifier circuits. SPICE modeling is available to students.
Prerequisites
Undergraduate courses in electricity and magnetism, circuit theory, and linear analysis.
Instructors: Baisden, Darlington

525.425  Laser Fundamentals
This course reviews electromagnetic theory and introduces the interaction of light and matter with an emphasis on laser theory. A fundamental background is established, necessary for advanced courses in optical engineering. Topics include Maxwell’s equations, total power law, introduction to spectroscopy, classical oscillator model, Kramers-Kroenig relations, line broadening mechanisms, rate equations, laser pumping and population inversion, laser amplification, laser resonator design, and Gaussian beam propagation.
Prerequisite
525.405 Intermediate Electromagnetics or equivalent.
Instructors: Thomas, Willitsford

525.427  Digital Signal Processing
Basic concepts of discrete linear shift-invariant systems are emphasized, including sampling, quantization, and reconstruction of analog signals. Extensive coverage of the Z-transform, discrete Fourier transform, and fast Fourier transform is given. An overview of digital filter design includes discussion of impulse invariance, bilinear transform, and window functions. Filter structures, finite length register effects, roundoff noise, and limit cycles in discrete-time digital systems are also covered.
Prerequisites
A working knowledge of Fourier and Laplace transforms.
Instructors: Ambrose, C. L. Edwards, M. L. Edwards
Online Option Available

525.428  Introduction to Digital CMOS VLSI
The objective of this course is to familiarize the student with the process of implementing a digital system as a full custom, integrated circuit. Upon completion, the student will be capable of completing skills to perform basic VLSI design from circuit concept to mask layout and simulation. Students will have the opportunity to have their projects fabricated at no cost through the MOSIS educational program. Topics include device fabrication, mask layout, introductory MOSFET physics, standard CMOS logic design, hierarchical IC design, and circuit simulation. Students will design, simulate, and do mask level layout of a circuit using a modern CMOS process.
Prerequisite
A course in digital design.
Instructor: Martin

525.430  Digital Signal Processing Lab
This course builds on the theory of digital signal processing. Opportunities are provided to work on specific applications of digital signal processing involving filtering, de-convolution, spectral estimation, and a variety of other techniques. Students may also suggest their own laboratory topics. Laboratory work involves developing signal processing systems on a personal
computer and using them with both real and simulated data. Questions related to hardware realizations are also considered.

**Prerequisite**
525.427 Digital Signal Processing.

**Instructors:** Fry, Newsome

### 525.431 Adaptive Signal Processing
This course examines adaptive algorithms (LMS, sequential regression, random search, etc.) and structures (filters, control systems, interference cancellers), and properties and uses of performance surfaces. Adaptive systems are implemented as part of the coursework. Problem exercises and a term project require computer use.

**Prerequisites**
525.427 Digital Signal Processing. Some knowledge of probability is helpful.

**Instructor:** Costabile

### 525.432 Analog Electronic Circuit Design II
This course extends the fundamental concepts of practical electronic circuit design developed in the course 525.424 Analog Electronic Circuit Design I. The general feedback method is reviewed. Students examine a wide range of devices, including operational amplifiers, A/D and D/A converters, switching regulators, and power supplies. Applications include low noise amplification, sensor conditioning, nonlinear transfer functions and analog computation, and power control.

**Prerequisite**
525.424 Analog Electronic Circuit Design I or permission of the instructor.

**Instructors:** Baisden, Darlington

### 525.434 High-Speed Digital Design and Signal Integrity
This course will discuss the principles of signal integrity and its applications in the proper design of high-speed digital circuits. Topics include the following: the definition and fundamentals of signal integrity, the fallacies believed by digital designers, ground/power planes, PCI series termination resistors, simulation software and signal integrity, ground bounce calculations, power bus noise, high-speed return signals, transmission lines, gate delay, differential pair skew, bypass capacitor layout, cable shield grounding, power-ground source impedance, open drain lines, series termination, equivalent circuit source impedance, terminators, crosstalk and SSO noise, gigabit ethernet specification, and short transmission line model.

**Prerequisites**
Thorough knowledge of digital design and basic circuit theory.

**Instructor:** Eaton

### 525.436 Optics and Photonics Laboratory
The objective of this course is to develop laboratory skills in optics and photonics by performing detailed experimental measurements and comparing these measurements to theoretical models. Error analysis is used throughout to emphasize measurement accuracy. A partial list of topics include: geometric optics, optical properties of materials, diffraction, interference, polarization, non-linear optics, fiber optics, non-linear fiber optics, optical detectors (pin, APD, PMT), optical sources (lasers, blackbodies, LEDs), phase and amplitude modulators, lidar, fiber-optic communications, and IR radiometry. The specific experiments will depend on hardware availability and student interest.

**Prerequisite**
525.491 Fundamentals of Photonics or 615.751 Modern Optics or equivalent.

**Instructors:** Sova, Terry

### 525.440 Satellite Communications Systems
This course presents the fundamentals of satellite communications link design and provides an overview of practical considerations. Existing systems are described and analyzed, including direct broadcast satellites, VSAT links, and Earth-orbiting and deep space spacecraft. Topics include satellite orbits, link analysis, antenna and payload design, interference and propagation effects, modulation techniques, coding, multiple access, and Earth station design.

**Prerequisite**
525.416 Communication Systems Engineering.

**Instructors:** DeBoy, Carmody

### 525.441 Computer and Data Communication Networks I
This course provides a comprehensive overview of computer and data communication networks, with emphasis on analysis and modeling. Basic communications principles are reviewed as they pertain to communication networks. Networking principles covered include layered network architecture, data encoding, static and multiaccess channel allocation methods (for LAN and WAN), ARQ retransmission strategies,
framing, routing strategies, transport protocols, and emerging high-speed networks.

**Prerequisites**

525.414 Probability and Stochastic Processes for Engineers and 525.416 Communication Systems Engineering, or equivalents.

**Instructors:** Hanson, Nasrabadi

**525.442 FPGA Design Using VHDL**

This lab-oriented course covers the design of digital systems using VHSCIC Hardware Description Language (VHDL) and its implementation in Field Programmable Gate Arrays (FPGAs). This technology allows cost-effective unique system realizations by enabling design reuse and simplifying custom circuit design. The design tools are first introduced and used to implement basic circuits. More advanced designs follow, focusing on integrating the FPGA with external peripherals, simple signal processing applications, utilizing soft-core processors, and using intellectual property (IP) cores. Projects will be assigned for course evaluation. Individual projects will be encouraged.

**Prerequisite**

A solid understanding of digital logic fundamentals.

**Instructors:** Hourani, Meitzler

**525.443 Real-Time Computer Vision**

This course introduces students to real-time computer vision through intensive use of the OpenCV open source computer vision framework. Students in the course will learn to quickly build applications that enable computers to “see” and make decisions based on the video stream input from a camera. By the end of the class, the students will be able to build a real-time system performing face detection and understand its implementation from in-class laboratory exercises. Topics include: camera models and camera calibration; Fourier analysis and image filtering; edge, line, and contour detection; Hough transforms; segmentation; optical flow, tracking, and particle filters; elements of machine learning and object recognition; and face detection. Students will be exposed to the mathematical tools that are most useful in the implementation of image processing and computer vision algorithms, from linear algebra, probability theory, and optimization theory.

**Prerequisites**

Knowledge of C or C++. Recommended prior exposure to probability theory, linear algebra, optimization techniques, and image processing.

**Instructors:** Burlina, DeMenthon

**525.445 Modern Navigation Systems**

This course explores the use of satellite, terrestrial, celestial, radio, magnetic, and inertial systems for the real-time determination of position, velocity, acceleration, and attitude. Particular emphasis is on the historical importance of navigation systems; avionics navigation systems for high performance aircraft; the Global Positioning System; the relationships between navigation, cartography, surveying, and astronomy; and emerging trends for integrating various navigation techniques into single, tightly coupled systems.

**Instructor:** Jablonski

**525.446 DSP Hardware Lab**

This course develops expertise and insight into the development of DSP processor solutions to practical engineering problems through hands-on experience. Structured exercises using DSP hardware are provided and used by the student to gain practical experience with basic DSP theory and operations. Course focus is on real-time, floating-point applications. This course is intended for engineers having EE or other technical backgrounds who desire to obtain practical experience and insight into the development of solutions to DSP problems requiring specialized DSP architectures.

**Prerequisites**

525.427 Digital Signal Processing and C programming experience.

**Instructors:** Haber, Wenstrand

**525.448 Introduction to Radar Systems**

This class introduces the student to the fundamentals of radar system engineering. The radar range equation in its many forms is developed and applied to different situations. Radar transmitters, antennas, and receivers are covered. The concepts of matched filtering, pulse compression, and the radar ambiguity function are introduced, and the fundamentals of radar target detection in a noise background are discussed. Target radar cross-section models are addressed, as well as the effects of the operating environment, including propagation and clutter. MTI and pulsed Doppler processing and performance are addressed. Range, angle, and Doppler resolution/accuracy, as well as fundamental tracking concepts, will also be discussed.

**Prerequisites**

525.414 Probability and Stochastic Processes for Engineers, 525.427 Digital Signal Processing, and a working knowledge of electromagnetics. Familiarity with MATLAB.

**Instructors:** Farthing, Griffith, Lum

Online Option Available

**525.451 Introduction to Electric Power Systems**

This course introduces and explains fundamentals of electrical power systems design and engineering. Phasors and their application to power systems analysis are reviewed. Concept of Per Unit system is introduced and applied to circuit calculations. Transformers and their application to electrical power transmission and distribution systems will be covered. Transmission line parameters, their calculation, and transmission line modeling are introduced. Power flow analysis computational techniques are covered. Short circuit analysis and the method of symmetrical components are introduced. The concept of power system protection and role of automatic relays will be covered. Transient stability of power systems will be discussed.
Renewable energy generation and the integration of renewable energy into the modern power grid will be introduced.

**Prerequisites**
Course in electrical networks; course in linear algebra and matrix operations.

**Instructor:** Alvandi

**525.466  Linear System Theory**
This course covers the structure and properties of linear dynamic systems with an emphasis on the single-input, single-output case. Topics include the notion of state-space, state variable equations, review of matrix theory, linear vector spaces, eigenvalues and eigenvectors, the state transition matrix and solution of linear differential equations, internal and external system descriptions, properties of controllability and observability and their applications to minimal realizations, state-feedback controllers, asymptotic observers, and compensator design using state-space and transfer function methods. An introduction to multi-input, multi-output systems is also included, as well as the solution and properties of time-varying systems.

**Prerequisites**
Courses in matrix theory and linear differential equations.

**Instructor:** Pue

**525.484  Microwave Systems and Components**
This course deals with the practical aspects of microwave systems and components. An overview of radar systems (including the effects of both standoff and escort jamming environments) is followed by an introduction to communication systems. The majority of the course treats the linear and nonlinear characteristics of individual components and their relation to system performance. Amplifiers, mixers, antennas, filters, and frequency sources are studied, as well as their interactions in cascade. Homework problems for each class reinforce the lecture material and may require use of computer-aided design software provided at the Dorsey Center.

**Prerequisite**
An undergraduate degree in electrical engineering or equivalent.

**Instructors:** Edwards, Kaul, Marks, Wilson
Online Option Available

**525.491  Fundamentals of Photonics**
This course provides the essential background in photonics necessary to understand modern photonic and fiber-optic systems. A fundamental background is established, necessary for advanced studies as well. Topics include electromagnetic optics, polarization and crystal optics, guided-wave optics, fiber optics, photons in semiconductors, semiconductors in photon sources and detectors, nonlinear optics, electro-optics, and acousto-optics.

**Prerequisite**
An undergraduate course in electromagnetic theory.

**Instructor:** Sosa

**525.707  Error Control Coding**
This course presents error-control coding with a view toward applying it as part of the overall design of a data communication or storage and retrieval system. Block, trellis, and turbo codes and associated decoding techniques are covered. Topics include system models, generator and parity check matrix representation of block codes, general decoding principles, cyclic codes, an introduction to abstract algebra and Galois fields, BCH and Reed-Solomon codes, analytical and graphical representation of convolutional codes, performance bounds, examples of good codes, Viterbi decoding, BCJR algorithm, turbo codes, and turbo code decoding.

**Prerequisites**
Background in linear algebra, such as 625.409 Matrix Theory; in probability, such as 525.414 Probability and Stochastic Processes for Engineers; and in digital communications, such as 525.416 Communication Systems Engineering. Familiarity with MATLAB or similar programming capability.

**Instructor:** Hammons

**525.708  Iterative Methods in Communications Systems**
Generalization of the iterative decoding techniques invented for turbo codes has led to the theory of factor graphs as a general model for receiver processing. This course will develop the general theory of factor graphs and explore several of its important applications. Illustrations of the descriptive power of this theory include the development of high performance decoding algorithms for classical and modern forward error correction codes (trellis codes, parallel concatenated codes, serially concatenated codes, low-density parity check codes). Additional applications include coded modulation systems in which the error correction coding and modulation are deeply intertwined as well as a new understanding of equalization techniques from the factor graph perspective.

**Prerequisites**
Background in linear algebra, such as 625.409 Matrix Theory; in probability, such as 525.414 Probability and Stochastic Processes for Engineers. Familiarity with MATLAB or similar programming capability.

**Instructor:** Hammons

**525.712  Advanced Computer Architecture**
This course covers topics essential to modern superscalar processor design. A review of pipelined processor design and hierarchical memory design is followed by advanced topics including the identification of parallelism in processes; multiple diversified functional units in a pipelined processor; static, dynamic; and hybrid branch prediction techniques; the Tomasulo algorithm for efficient resolution of true data dependencies; advanced data flow techniques with and without speculative execution; multiprocessor systems; and multithreaded processors.

**Prerequisites**
525.412 Computer Architecture or equivalent.

**Instructor:** Staff
525.713  **Analog Integrated Circuit Design**  
This course focuses on CMOS analog integrated circuits. Topics include devices, subthreshold operation, simple amplifiers, reference circuits, and differential amplifiers. Voltage and current mode techniques are introduced for the implementation of analog signal processing. Circuit analysis methodologies are stressed and complemented with design tools for layout, simulation, and verification. A final project involves the design of a small circuit, with the possibility of fabrication through MOSIS. 

**Prerequisites**  
525.424 Analog Electronic Circuit Design I or equivalent, and 525.428 Introduction to CMOS VLSI.  

**Instructor:** Martin

525.718  **Multirate Signal Processing**  
Multirate signal processing techniques find applications in areas such as communication systems, signal compression, and sub-band signal processing. This course provides an in-depth treatment of both the theoretical and practical aspects of multirate signal processing. The course begins with a review of discrete-time systems and the design of digital filters. Sample rate conversion is covered, and efficient implementations using polyphase filters and cascade integrator comb (CIC) filters are considered. The latter part of the course treats filter bank theory and implementation, including quadrature mirror, conjugate quadrature, discrete Fourier transform, and cosine modulated filter banks along with their relationship to transmultiplexers.  

**Prerequisites**  
525.427 Digital Signal Processing or equivalent and working knowledge of MATLAB.  

**Instructors:** Jennison, Younkins

525.721  **Advanced Digital Signal Processing**  
The fundamentals of discrete-time statistical signal processing are presented in this course. Topics include estimation theory, optimal linear filter theory, recursive methods for optimal filters, classical and modern spectrum analysis, and adaptive filtering, as well as the singular value decomposition and its applications. Basic concepts of super-resolution methods are described.  

**Prerequisites**  
525.414 Probability and Stochastic Processes for Engineers, 525.427 Digital Signal Processing, and the basics of linear algebra. Familiarity with a scientific programming language such as MATLAB.  

**Instructors:** Najmi, Rodriguez

525.722  **Wireless and Mobile Cellular Communications**  
In this course, students examine fundamental concepts of mobile cellular communications and specifics of current and proposed U.S. cellular systems. Topics include frequency reuse; call processing; propagation loss; multipath fading and methods of reducing fades; error correction requirements and techniques; modulation methods; FDMA, TDMA, and CDMA techniques; microcell issues; mobile satellite systems; and IMT-2000.  

**Prerequisites**  
525.414 Probability and Stochastic Processes for Engineers or equivalent and 525.416 Communication Systems Engineering.  

**Instructor:** Zueldorff

Online Option Available

525.723  **Computer and Data Communication Networks II**  
This course emphasizes the mathematical analysis of communication networks. Queuing theory and its applications are covered extensively, including the topics of M/M/1 systems, M/G/1 systems, Burke’s theorem, and Jackson’s theorem. Multiaccess communication is discussed, including the topics of Aloha systems and packet radio networks. Students also explore network routing including the Bellman-Ford algorithm, Dijkstra’s algorithm, and optimal routing.  

**Prerequisite**  
525.441 Computer and Data Communication Networks I.  

**Instructor:** Hanson

525.724  **Introduction to Pattern Recognition**  
This course focuses on the underlying principles of pattern recognition and on the methods of machine intelligence used to develop and deploy pattern recognition applications in the real world. Emphasis is placed on the pattern recognition application development process, which includes problem identification, concept development, algorithm selection, system integration, and test and validation. Machine intelligence algorithms to be presented include feature extraction and selection, parametric and non-parametric pattern detection and classification, clustering, artificial neural networks, support vector machines, rule-based algorithms, fuzzy logic, genetic algorithms, and others. Case studies drawn from actual machine intelligence applications will be used to illustrate how methods such as pattern detection and classification, signal taxonomy, machine vision, anomaly detection, data mining, and data fusion are applied in realistic problem environments. Students will use the MATLAB programming language and the data from these case studies to build and test their own prototype solutions.  

**Prerequisites**  
525.414 Probability and Stochastic Processes for Engineers or equivalent. A course in digital signal or image processing is recommended, such as 525.427 Digital Signal Processing, 525.419 Introduction to Digital Image and Video Processing, 525.443 Real-Time Computer Vision, or 525.746 Image Engineering.  

**Instructor:** Baumgart
525.725  **Power Electronics**  
This course covers the design and analysis of DC-to-DC switching converters. Topics include topology selection for various applications, steady state operation including continuous versus discontinuous operation, fundamentals of control loop design including both voltage mode and current mode control, fundamentals of magnetic design including how to minimize losses, input and output filter design, pulse-width modulation chip selection, diode and transistor part selection and the associated effects of part non-idealities on the converter performance, and modeling of the converter. The complete process of converter design and implementation is presented including requirement specification and testing verification needed to evaluate the converter performance such as efficiency, regulation, line rejection, EMI/EMC measurements, and stability measurements. Two labs that will give the student hands-on experience with design and testing of a typical DC-to-DC converter are part of the course.  
**Prerequisite**  
525.424 Analog Electronic Circuit Design I or equivalent.  
**Instructor:** Katsis

525.728  **Detection and Estimation Theory**  
Both hypothesis testing and estimation theory are covered. The course starts with a review of probability distributions, multivariate Gaussians, and the central limit theorem. Hypothesis testing areas include simple and composite hypotheses and binary and multiple hypotheses. In estimation theory, maximum likelihood estimates and Bayes estimates are discussed. Practical problems in radar and communications are used as examples throughout the course.  
**Prerequisites**  
525.414 Probability and Stochastic Processes for Engineers or equivalent.  
**Instructors:** Banerjee, Marble  
**Online Option Available**

525.735  **MIMO Wireless Communications**  
This course presents the fundamental concepts and techniques of multiple-input multiple-output (MIMO) communications over wireless communication channels. MIMO communications, which involve the use of multiple antennas at the transmitter and receiver, employ the use of signal processing techniques to enhance the reliability and capacity of communication systems without increasing the required spectral bandwidth. MIMO techniques are currently used or planned in many commercial and military communications systems. Topics include the derivation and application of the theoretical MIMO communications capacity formula; channel fading and multipath propagation; the concepts of transmit and receive space diversity; space-time block coding, with a special emphasis on Alamouti coding; space-time trellis coding; spatial multiplexing; and fundamentals of OFDM modulation and its relation to MIMO communications. Examples and applications will be presented as well as related MATLAB homework assignments.  
**Prerequisites**  
525.416 Communication Systems Engineering; 525.414 Probability and Stochastic Processes for Engineers, or the equivalent. In addition, a working knowledge of MATLAB is required.  
**Instructor:** Hampton

525.736  **Smart Antennas for Wireless Communications**  
The theory and implementation of smart antennas is explored including electromagnetic principles, array signal processing, random processes, channel characterization, spectral estimation, and adaptive algorithms. The fundamentals of electromagnetics, antenna elements, antenna arrays, sidelobe cancellation, and adaptive antennas methods will be covered. MATLAB will be used for instruction, simulation, and homework.  
**Prerequisites**  
525.414 Probability and Stochastic Processes, 525.418 Antenna Systems. Knowledge of MATLAB will be helpful.  
**Instructor:** Roddewig

525.738  **Advanced Antenna Systems**  
This course is designed to follow 525.418 Antenna Systems. Advanced techniques needed to analyze antenna systems are studied in detail. Fourier transforms are reviewed and applied to antenna theory and array distributions. The method of moments is studied and used to solve basic integral equations employing different basis functions. Green's functions for patch antennas are formulated in terms of Sommerfeld-like integrals. Techniques such as saddle-point integration are presented. Topics addressed include computational electromagnetics, leaky and surface waves, mutual coupling, and Floquet modes. Students should be familiar with complex variables (contour integration), Fourier transforms, and electromagnetics from undergraduate studies.  
**Prerequisites**  
525.418 Antenna Systems.  
**Instructor:** Weiss

525.742  **System-on-a-Chip FPGA Design Laboratory**  
This lab-oriented course will focus on the design of large-scale system-on-a-chip (SOC) solutions within field-programmable gate arrays (FPGAs). Modern FPGA densities and commercially available cores enable a single developer to design highly complex systems within a single FPGA. This class will provide the student with the ability to design and debug these inherently complex systems. Topics will include high-speed digital signal processing, embedded processor architectures, customization of soft-core processors, interfacing with audio and video sensors, communications interfaces, and networking. The optimum division of algorithms between hardware and software will be discussed, particularly the ability to accelerate software algorithms by building custom hardware. Many
labs will center around a common architecture which includes signal processing algorithms in the FPGA fabric, controlled by an embedded processor that provides user interfaces and network communication. The first section of the course will be spent experimenting with different building blocks for constructing SOCs. Students will spend later class sessions working in teams on self-directed SOC design projects. Industry standard tools will be used.

**Prerequisites**

525.442 FPGA Design Using VHDL and familiarity with C programming.

**Instructors:** Haber, Wenstrand

**525.743 Embedded Systems Development Laboratory**

This project-based laboratory course involves the development of embedded system prototypes. Typical projects contain combinations of the following components: transducers, analog front ends, microcontrollers and processors, CPLDs, FPGAs, digital signal processors, electrical interfaces, wired or wireless connectivity, printed circuit boards required for integration and test, and software/firmware modules needed to operate designed system. The laboratory activity is a backdrop used to teach key aspects of the development process such as: documentation, realistic use of requirements, design partition, integration strategy, interface design, peer review, risk mitigation, testability, extensibility, distributed development teams, and design strategies to accommodate available resources. Software development topics such as source control, testability, and deployment will also be covered. Instructors will select the design topic for each semester and students will focus their effort on hardware, software, or both, based upon their preference and instructor approval.

**Prerequisites**

An undergraduate degree in electrical or computer engineering or computer science, 525.412 Computer Architecture, and working knowledge of C or C++ or instructor’s approval.

**Instructor:** Houser

**525.744 Passive Emitter Geo-Location**

This course covers the algorithms used to locate a stationary RF signal source, such as a radar, radio, or cell phone. The topics covered include: a review of vectors, matrices, and probability; linear estimation and Kalman filters; nonlinear estimation and extended Kalman filters; robust estimation; data association; measurement models for direction of arrival, time difference of arrival, and frequency difference of arrival; geo-location algorithms; and performance analysis. Most of the course material is developed in planar Cartesian coordinates for simplicity; however, the extension to WGS84 coordinates is provided to equip the students for practical applications. Homework consists of both analytical problems and ones that require computer simulation using software such as MATLAB.

**Prerequisites**

525.414 Probability and Stochastic Processes for Engineers; an undergraduate course in linear algebra/matrix theory; familiarity with MATLAB.

**Instructor:** Grabbe

**525.745 Applied Kalman Filtering**

Theory, analysis, and practical design and implementation of Kalman filters are covered, along with example applications to real-world problems. Topics include a review of random processes and linear system theory; Kalman filter derivations; divergence analysis; numerically robust forms; suboptimal filters and error budget analysis; prediction and smoothing; cascaded, decentralized, and federated filters; linearized, extended, second order, and adaptive filters; and case studies in GPS, inertial navigation, and ballistic missile tracking.

**Prerequisites**

525.414 Probability and Stochastic Processes for Engineers and 525.466 Linear System Theory or equivalents. Knowledge of MATLAB (or equivalent software package).

**Instructors:** Samsundar, Watkins

**525.746 Image Engineering**

The overall goal of the course is to provide the student with a unified view of images, concentrating on image creation, and image processing. Optical, photographic, analog, and digital image systems are highlighted. Topics include image input, output, and processing devices; visual perception; video systems; and fundamentals of image enhancement and restoration. Coding, filtering, and transform techniques are covered, with applications to remote sensing and biomedical problems.

**Prerequisites**

525.427 Digital Signal Processing or equivalent and knowledge of linear systems.

**Instructors:** Bankman, Miller

**525.747 Speech Processing**

This course emphasizes processing of the human speech waveform, primarily using digital techniques. Theory of speech production and speech perception as related to signals in time and frequency-domains is covered, as well as the measurement of model parameters, short-time Fourier spectrum, and linear predictor coefficients. Speech coding, filtering, and transform techniques are discussed. Application areas include telecommunications telephony, Internet VOIP, and man–machine interfaces. Considerations for embedded realization of the speech processing system will be covered as time permits. Several application-oriented software projects will be required.

**Prerequisites**

525.427 Digital Signal Processing and 525.414 Probability and Stochastic Processes for Engineers. Background in linear algebra and MATLAB is helpful.

**Instructor:** Carmody
525.751  **Software Radio for Wireless Communications**

This course will explore modern software radio technology and implementation. Digital signal processors and field-programmable gate arrays have traditional uses in radar and digital signal and system processing. However, with advances in design they have started to be employed as key components in software radios. We will explore concepts and techniques that are key to implementing traditionally analog processing functions and ASICs in easily reconfigured digital logic. Students will design software radio functions and algorithms and program FPGA development kits using industry standard tools and techniques. A semester project involving software GPS radio or other topics is required.

**Prerequisites**
525.438 Introduction to Wireless Technology or 525.416 Communication Systems Engineering; 525.427 Digital Signal Processing; and working knowledge of MATLAB and Simulink.

**Instructors:** Chew, Roddewig

525.753  **Laser Systems and Applications**

This course provides a comprehensive treatment of the generation of laser light and its properties and applications. Topics include specific laser systems and pumping mechanisms, nonlinear optics, temporal and spatial coherence, guided beams, interferometric and holographic measurements, and remote sensing.

**Prerequisites**
525.425 Laser Fundamentals.

**Instructors:** Bankman, Thomas

525.754  **Wireless Communication Circuits**

In this course, students examine modulator and demodulator circuits used in communication and radar systems. A combination of lectures and laboratory experiments addresses the analysis, design, fabrication, and test of common circuits. Signal formats considered include phase and frequency shift keying, pseudo-random codes, and the linear modulations used in analog systems.

**Prerequisites**
525.416 Communication Systems Engineering or 525.484 Microwave Systems and Components or permission of the instructor.

**Instructors:** Houser, Kaul, Tobin

525.756  **Optical Propagation, Sensing, and Backgrounds**

This course presents a unified perspective on optical propagation in linear media. A basic background is established using electromagnetic theory, spectroscopy, and quantum theory. Properties of the optical field and propagation media (gases, liquids, and solids) are developed, leading to basic expressions describing their interaction. The absorption line strength and shape and Rayleigh scattering are derived and applied to atmospheric transmission, optical window materials, and propagation in water-based liquids. A survey of experimental techniques and apparatus is also part of the course. Applications are presented for each type of medium, emphasizing remote sensing techniques and background noise. Computer codes such as LOWTRAN, FASCODE, and OPTIMATR are discussed.

**Prerequisites**
Undergraduate courses on electromagnetic theory and elementary quantum mechanics. A course on Fourier optics is helpful.

**Instructor:** Thomas

525.759  **Image Compression, Packet Video, and Video Processing**

This course provides an introduction to the basic concepts and techniques used for the compression of digital images and video. Video compression requirements, algorithm components, and ISO Standard video processing algorithms are studied. Image compression components that are used in video compression methods are also identified. Since image and video compression is now integrated in many commercial and experimental video processing methods, knowledge of the compression methods’ effects on image and video quality are factors driving the usability of that data in many data exploitation activities. Topics to be covered include introduction to video systems, Fourier analysis of video signals, properties of the human visual system, motion estimation, basic video compression techniques, video communication standards, and error control in video communications. Video processing applications that rely on compression algorithms are also studied. A mini-project is required.

**Prerequisites**
525.427 Digital Signal Processing.

**Instructor:** Beser

Online Option Available

525.761  **Wireless and Wireline Network Integration**

This course investigates the integration of wireless and wireline networks into seamless networks. The current telecommunications environment in the United States is first discussed, including the state of technology and regulations as they apply to the wireless and wireline hybrid environment. Then each type of these hybrid networks is discussed, including its components, network services, architecture, and possible evolution, as well as important concepts that support the evolution of networks. The integration of wired network advance intelligence, wireless network mobility, and long distance capabilities are shown to provide many new combinations of wired and wireless services to users.

**Prerequisites**
525.408 Digital Telephony or 525.416 Communication Systems Engineering, or permission of instructor.

**Instructor:** R. Lee
525.762 Signal Processing with Wavelets
This course covers the mathematical framework for wavelets with particular emphasis on algorithms and implementation of the algorithms. Concepts of frames, orthogonal bases, and reproducing kernel Hilbert spaces are introduced first, followed by an introduction to linear systems for continuous-time and discrete-time. Next, time, frequency, and scale localizing transforms are introduced, including the windowed Fourier transform and the continuous wavelet transform (CWT). Discretized CWT are studied next in the forms of the Haar and the Shannon orthogonal wavelet systems. General multiresolution analysis is introduced and the time domain and frequency domain properties of orthogonal wavelet systems are studied with examples of compact support wavelets. The discrete wavelet transform (DWT) is introduced and implemented. Biorthogonal wavelet systems are also described. Orthogonal wavelet packets are discussed and implemented. Wavelet regularity and the Daubechies construction is presented next. Finally the 2D DWT is discussed and implemented. Applications of wavelet analysis to denoising and image compression are discussed together with an introduction to image coding.

Prerequisites
525.427 Digital Signal Processing and the basics of linear systems.

Instructor: Najmi

525.763 Applied Nonlinear Systems
This course provides an introduction to nonlinear systems, including differences between linear and nonlinear systems; mathematical preliminaries; equilibrium points of nonlinear systems; phase plane analysis and limit cycles; stability definitions for nonlinear systems; Lyapunov's indirect and direct methods; stability of autonomous and non-autonomous systems; describing function analysis; nonlinear control design including sliding-mode, adaptive, and nonlinear robust control; and applications of nonlinear control design.

Prerequisites
525.409 Continuous Control Systems or equivalent.

Instructor: Ambrose

525.768 Wireless Networks
This is a hands-on course that integrates teaching of concepts in wireless LANs as well as offering students, in an integrated lab environment, the ability to conduct laboratory experiments and design projects that cover a broad spectrum of issues in wireless LANs. The course will describe the characteristics and operation of contemporary wireless network technologies such as the IEEE 802.11 and 802.11s wireless LANs and Bluetooth wireless PANs. Laboratory experiments and design projects include MANET routing protocols, infrastructure and MANET security, deploying hotspots, and intelligent wireless LANs. The course will also introduce tools and techniques to monitor, measure, and characterize the performance of wireless LANs as well as the use of network simulation tools to model and evaluate the performance of MANETs.

Prerequisite
525.441 Computer and Data Communication Networks I or 605.471 Principles of Data Communications Networks.

Instructor: Refaei

525.770 Intelligent Algorithms
Intelligent algorithms are, in many cases, practical alternative techniques for tackling and solving a variety of challenging engineering problems. For example, Fuzzy Control techniques can be utilized to construct nonlinear controllers via the use of heuristic information when information of the physical system is limited. Such heuristic information may come, for instance, from an operator who has acted as a “human-in-the-loop” controller for the process. This course investigates a number of concepts and techniques commonly referred to as Intelligent Algorithms, discusses the underlying theory of these methodologies when appropriate, and takes an engineering perspective and approach to the design, analysis, evaluation, and implementation of intelligent systems. Fuzzy Systems, Genetic Algorithms, Particle Swarm and Ant Colony Optimization Techniques, and Neural Networks are the primary concepts discussed in this course, and several engineering applications are presented along the way. Expert (rule-based) Systems are also discussed within the context of Fuzzy Systems. An Intelligent Algorithms research paper must be selected from the existing literature, implemented by the student, and presented as a final project. Student familiarity of system-theoretic concepts is desirable.

Instructor: Palumbo

525.771 Propagation of Radio Waves in the Atmosphere
This course examines various propagation phenomena that influence transmission of radio frequency signals between two locations on earth and between satellite-earth terminals, with a focus on applications. Frequencies above 30 MHz are considered with emphasis on microwave and millimeter propagation. Topics include free space transmission, propagation, and reception; effects on waves traversing the ionosphere; and attenuation due to atmospheric gases, rain, and clouds. Brightness temperature concepts are discussed, and thermal noise introduced into the receiver system from receiver hardware and from atmospheric contributions are examined. Also described are reflection and diffraction effects by land terrain and ocean, multipath propagation, tropospheric refraction, propagation via surface and elevated ducts, scatter from fluctuations of the refractive index, and scattering due to rain. Atmospheric dynamics that contribute to the various types of propagation conditions in the troposphere are described.

Prerequisite
An undergraduate degree in electrical engineering or equivalent.

Instructor: Dockery
525.772 Fiber-Optic Communication Systems
This course investigates the basic aspects of fiber-optic communication systems. Topics include sources and receivers, optical fibers and their propagation characteristics, and optical fiber systems. The principles of operation and properties of optoelectronic components, as well as the signal guiding characteristics of glass fibers, are discussed. System design issues include terrestrial and submerged point-to-point optical links and fiber-optic networks.

Prerequisite
525.491 Fundamentals of Photonics.

Instructor: Sova

525.774 RF and Microwave Circuits I
In this course, students examine RF and microwave circuits appropriate for wireless communications and radar sensing. It emphasizes the theoretical and experimental aspects of microstrip design of highly integrated systems. Matrix analysis and computer-aided design techniques are introduced and used for the analysis and design of circuits. Circuits are designed, fabricated, and tested, providing a technically stimulating environment in which to understand the foundational principles of circuit development. Couplers, modulators, mixers, and calibrated measurements techniques are also covered.

Prerequisites
525.423 Principles of Microwave Circuits or 525.420 EM Transmission Systems.

Instructors: Penn, Thompson

525.775 RF and Microwave Circuits II
This course builds upon the knowledge gained in 525.774 RF and Microwave Circuits I. Here there is a greater emphasis on designs involving active components. Linear and power amplifiers and oscillators are considered, as well as stability, gain, and their associated design circles. The course uses computer-aided design techniques, and students fabricate and test circuits of their own design.

Prerequisites
525.774 RF and Microwave Circuits I.

Instructors: Penn, Thompson

525.776 Information Theory
Course topics include measure of information, noiseless coding, communication channels and channel capacity, the noisy channel coding theorem, bounds on the performance of communications systems, the Gaussian and binary symmetric channels, feedback communications systems, and rate distortion theory.

Prerequisite
525.414 Probability and Stochastic Processes for Engineers or equivalent.

Instructor: Kinney

525.777 Control System Design Methods
This course examines recent multivariable control system design methodologies and how the available techniques are synthesized to produce practical system designs. Both the underlying theories and the use of computational tools are covered. Topics include review of classical control system design and linear system theory, eigenstructure assignment, the linear quadratic regulator, the multivariable Nyquist criterion, singular value analysis, stability and performance robustness measures, loop transfer recovery, H-infinity design, and mu-synthesis. An introduction to nonlinear techniques includes sliding mode control and feedback linearization. Recent papers from the literature are discussed. Each student will be assigned a design project using PC-based design and analysis software.

Prerequisites
525.466 Linear System Theory and 525.409 Continuous Control Systems or the equivalent.

Instructor: Pue

525.778 Design for Reliability, Testability, and Quality Assurance
The design of reliable and testable systems, both analog and digital, is considered at the component, circuit, system, and network levels. Using numerous real-world examples, the tradeoffs between redundancy, testability, complexity, and fault tolerance are explored. Although the emphasis is predominantly on electronics, related examples from the aerospace and software industries are included. The concepts of fault lists, collapsed fault lists, and other techniques for reducing the complexity of fault simulation are addressed. A quantitative relationship between information theory, error correction codes, and reliability is developed. Finally, the elements of a practical quality assurance system are presented. In addition to homework assignment, students will conduct an in-depth, quantitative case study of a practical system of personal interest.

Instructor: Jablonski

525.779 RF Integrated Circuits
This course covers the RFIC design process focusing on the RF/Microwave portion of RFIC. An overview of digital circuits and digital signal processing will be given along with semi-conductor fabrication, device models, and RF/Microwave design techniques using a typical SiGe process. Part of the course will involve student design projects using Analog Office software to design amplifiers, mixers, etc.

Prerequisite
525.774 RF and Microwave Circuits I or equivalent.

Instructors: Penn, Wilson

525.780 Multidimensional Digital Signal Processing
The fundamental concepts of multidimensional digital signal processing theory as well as several associated application areas are covered in this course. The course begins with an
investment of continuous-space signals and sampling theory in two or more dimensions. The multidimensional discrete Fourier transform is defined, and methods for its efficient calculation are discussed. The design and implementation of two-dimensional non-recursive linear filters are treated. The final part of the course examines the processing of signals carried by propagating waves. This section contains descriptions of computed tomography and related techniques and array signal processing. Several application oriented software projects are required.

Prerequisites
525.414 Probability and Stochastic Processes for Engineers and 525.427 Digital Signal Processing or equivalents. Knowledge of linear algebra and MATLAB is helpful.

Instructor: Jennison

525.783 Spread-Spectrum Communications
This course presents an analysis of the performance and design of spread-spectrum communication systems. Both direct-sequence and frequency-hopping systems are studied. Topics include pseudonoise sequences, code synchronization, interference suppression, and the application of error-correcting codes. The use of code-division multiple access in digital cellular systems is examined. The relationships between spread spectrum, cryptographic, and error correction systems are explored. The mathematics of pseudo-random sequences used as spreading codes is compared with the mathematics of complex numbers with which students are already familiar.

Prerequisites
525.416 Communication Systems Engineering. Students should have knowledge of material covered in 525.201 and 525.202.

Instructor: Jablonski

Online Option Available

525.786 Human Robotics Interaction
This course provides an investigation of human–robot interaction and prosthetic control, with a focus on advanced man–machine interfaces including neural signal processing, electromyography, and motion tracking interfaces for controlling and receiving feedback from robotic devices. The course will also cover human physiology and anatomy, signal processing, intent determination, communications between the human and the device, haptic feedback, and telepresence. It is designed to be a hands-on course with class time spent in the dedicated robotics lab designing interfaces and performing experiments in a Virtual Integration Environment (VIE) and with robotic devices. Additional time in the lab, outside of class time, may be required to complete the course project. Programming for the class will be in MATLAB and Simulink.

Prerequisites
525.427 Digital Signal Processing, knowledge of linear algebra, and familiarity with MATLAB and Simulink.

Instructors: Armiger, Lesho

525.787 Microwave Monolithic Integrated Circuit (MMIC) Design
This course is for advanced students who have a background in microwave circuit analysis and design techniques and are familiar with modern microwave computer-aided engineering tools. The course covers the monolithic implementation of microwave circuits on GaAs substrates including instruction on processing, masks, simulation, layout, design rule checking, packaging, and testing. The first part of the course includes information and assignments on the analysis and design of MMIC chips. The second part consists of projects in which a chip is designed, reviewed, and evaluated in an engineering environment, resulting in a chip mask set that is submitted for foundry fabrication.

Prerequisite
525.775 RF and Microwave Circuits II.

Instructor: Penn

525.788 Power Microwave Monolithic Integrated Circuit (MMIC) Design
The Power MMIC course covers additional circuit design techniques applicable to MMICs (and microwave circuits in general). It is an extension of RF and Microwave Circuits I and II and Microwave Monolithic Integrated Circuit (MMIC) Design, though for students with a microwave background, these particular courses are not prerequisites. The topics covered include broadband matching, optimum loads for efficiency and low intermodulation products, odd mode oscillations, details of nonlinear modeling, time domain simulation of nonlinear circuits, and thermal effects. Students do need to have a background in microwave measurements and microwave CAD tools. No project is required, but there is structured homework involving power MMIC design completed by the student using a foundry library. The course is given in the spring; it is not given every year.

Instructor: Dawson

525.789 Digital Satellite Communications
This course covers advanced topics in satellite communication systems, with emphasis on digital communications. After a review of basic concepts, the following topics are addressed: the distinctions between digital and nondigital communications systems; reasons for preferring some forms of modulation and coding over others for spacecraft implementation; the relationships between spectrum management, signal propagation characteristics, orbitology, constellation design, and communications system design; the use of spread spectrum (CDMA and frequency-hopping), TDMA, and FDMA architectures; protocol design and usage; GPS; digital audio radio satellites; the use of geostationary satellites for mobile telephone systems; satellite television; and VSAT terminals.

Prerequisites
525.416 Communication Systems Engineering is required, and 525.440 Satellite Communications Systems is recom-
mended. Students should have knowledge of material covered in 525.201 and 525.202.

Instructor: Jablonski

525.791 Microwave Communications Laboratory
Concepts involving the design and fabrication of microwave subsystems are introduced in this laboratory course, including image rejection mixers, local oscillators, phase locked loops, and microstrip filters. A communication project is required, such as design and fabrication of an L-band WEFAX (weather facsimile) receiver or a C-band AMSAT (amateur communications satellite) converter. Modern microwave analyzing instruments are used by the students to evaluate the performance of the project subsystems.

Prerequisite 525.774 RF and Microwave Circuits I.

Instructors: Everett, Fazi

525.792 Electro-Optical Systems
This course covers the analysis and conceptual design of practical electro-optical (EO) systems. Although EO technology is emphasized, the fundamentals of radiometry and optical radiation are also described to provide an understanding of the essential physics, whereas background characterization and atmospheric propagation are only briefly covered. Basic EO system component performance is characterized parametrically for detection, tracking, communications, and imaging. Passive (infrared imaging) and active (laser radar and laser communication systems) are stressed. Components considered in these systems include basic telescopes and optics, focal plane arrays, laser diodes, photodiode receivers, and laser scanners.

Prerequisite 615.751 Modern Optics or the equivalent.

Instructors: Boone, Edwards

525.793 Advanced Communication Systems
In this course, students receive an introduction to digital baseband and bandpass modulation and demodulation/detection. Digital communication system performance is then evaluated using link budget analysis. Additional topics may include channel coding, equalization, synchronization, modulation and coding tradeoffs, multiplexing, and multiple access.

Prerequisites 525.414 Probability and Stochastic Processes for Engineers; 525.416 Communication Systems Engineering.

Instructor: Carmody

525.796 Introduction to High-Speed Electronics and Optoelectronics
This course provides the student with the fundamental concepts needed to address issues in both the design and test of high-speed electronic and optical systems. Topics include electronic devices and circuits used at microwave and millimeter frequencies, optical active devices and waveguide technology, electronic and optical pulse generation techniques, high-speed packaging design, and testing techniques.

Prerequisites Undergraduate courses in circuits and systems.

Instructors: Sova, Vichot

525.797 Advanced Optics and Photonics Laboratory
The objective of this course is to develop advanced experimental techniques in optics and photonics. Students will work in teams of two or three on in-depth optical experiments consisting of multiple parts that include constructing experimental apparatus and developing data acquisition and analysis software. Example experiments include coherent and incoherent laser radar, laser vibrometry, fiber lasers dynamics, high-resolution microscopy using Fourier optics, 3D interferometric imaging, optical properties of materials, 10 Gbps WDM fiber communication system, optical tomographic imaging in highly diffuse media, speckle interferometry, mode-locked and soliton lasers, and non-linear fiber optics. The specific experiments will depend on hardware availability and student interest.

Prerequisite 525.436 Optics and Photonics Laboratory or equivalent.

Instructors: Sova, Terry

525.801 Special Project I
In individual cases, special arrangements can be made to carry out a project of significant scope in lieu of a formal course. Further information is available from the program chair. Such arrangements are made relatively infrequently. This course number should be used for the first registration of a student in any special project.

Course Notes To be assured consideration for any term, project proposals should reach the program chair by the end of the registration period.

Instructor: Staff

525.802 Special Project II
This course number should be used for the second registration of a student in any special project. (See course 525.801 Special Project I for a further description.)

Course Notes To be assured consideration for any term, project proposals should reach the program chair by the end of the registration period.

Instructor: Staff

525.803/804 Electrical and Computer Engineering Thesis
These two courses are designed for students in the electrical and computer engineering graduate program who wish to
undertake a thesis project after completing all other requirements for their degree. Students work with an advisor to conduct independent research and development in ECE leading to a written thesis and oral presentation to a thesis committee. The intent of the research may be to advance the body of knowledge in one of the technology areas in the ECE program. Students accepted into this course will have off-hours access to ECE facilities at the Applied Physics Laboratory and the Dorsey Center. A limited amount of support for research materials is available.

**Prerequisites**
Completion of all other courses applicable to the ECE graduate degree and approval of the ECE program chair and vice chair. The thesis option is appropriate for highly motivated students with strong academic records.

**Instructor:** Staff
Environmental Engineering, Science, and Management

In a world undergoing rapid ecological transformation, the role of environmental engineers, scientists, and planners has become increasingly prominent. In the Johns Hopkins tradition of excellence, the graduate part-time program in environmental engineering, science, and management is one of the most comprehensive and rigorous professional environmental engineering, science, technology, planning, and management programs in the nation. Through the use of interactive learning technologies and online course delivery, the EP Environmental Program aims to make this academic curriculum accessible to students throughout the world. The program accommodates working professionals who wish to complete graduate degree requirements without interrupting their careers and provides them with skills necessary to address a broad array of modern environmental issues and capitalize on environmental protection and remediation opportunities presented by technology. Common to all program activities is recognition of the importance of obtaining a strong quantitative background in the environmental engineering, science, and management principles that govern environmental processes.

In the program, students obtain an up-to-date level of understanding in the following interrelated academic fields:

- Study of physical, chemical, and biological processes fundamental to understanding the environment fate and engineered treatment of environmental contaminants
- Understanding the source and nature of waste materials that contribute to air, soil, and water pollution and relevant management and control technologies
- Advanced study of the science, impacts, mitigation, adaptation, and policy relevant to climate change and global environmental sustainability, energy planning, alternative energy technologies, sustainable development, and next-generation buildings
- Study of the transport and transformation of contaminants through environmental pathways
- Knowledge of the pollution prevention and technologies and designs associated with the treatment and disposal of waste materials
- Rigorous study of the connection between the engineering and scientific aspects of environmental problems and decision-making processes

Improved understanding in all of these areas is achieved through a quantitative program built around the common theme of engineering and science in support of environmental decision making and management.

Program Committee

Hedy V. Alavi, Program Chair
Environmental Engineering, Science, and Management Engineering for Professionals
Whiting School of Engineering

The entire faculty of the Whiting School’s Department of Geography and Environmental Engineering functions as the program committee for EP’s Environmental Engineering, Science, and Management program. This committee ensures that instruction in the part-time program is of the highest quality and is continually enhanced in a manner consistent with parallel developments in the full-time program.

Faculty

The program features about 50 highly qualified faculty members. Each is a distinguished and experienced professional with the highest academic degree in their field of expertise, and each has demonstrated a strong commitment to excellence in teaching. Many of the outstanding full-time faculty from the nationally renowned Department of Geography and Environmental Engineering at Johns Hopkins participate as program instructors. In addition, the program includes several directors, senior scientists, engineers, researchers, and attorneys affiliated with the U.S. Environmental Protection Agency, Maryland Department of the Environment, U.S. Department of Energy, National Institutes of Health, National Research Council, U.S. Department of Defense, Nuclear Regulatory Agency, U.S. Army Corps of Engineers, and many leading environmental consulting companies such as EA Engineering, Science and Technology, KCI Technologies, Bechtel Corporation, CH2M Hill, Lockheed Martin Corporation, and Northrop Grumman. Please see Faculty (page 185) for the list of active faculty members and their affiliations.

Environmental Engineering, Science, and Management—Online

To facilitate the accessibility of program offerings, the Master of Science in Environmental Planning and Management and the Master of Science in Environmental Engineering and Science are available fully online. The requirements for other degrees and certificates offered may be fulfilled online; students should consult with an academic services specialist for the full list of affected programs.

Students completing the joint Master of Science in Applied Economics from JHU Advanced Academic Programs and the Graduate Certificate in Environmental Planning and Management may complete the graduate certificate portion of the program online through EP.

Students interested in pursuing the dual Master of Business Administration through the Carey Business School, which combines with either the MS in Environmental Planning and Management, the MS in Environmental Engineering and Science, or the Master of Environmental Engineering,
may complete the Master of Science portion of the program online through EP.

There are numerous courses in the Environmental Engineering, Science, and Management program offered in an online format, and more courses are continually being developed. This increases the flexibility of course offerings for all programs.

**Degrees and Certificates**
The program offers professional non-thesis degrees in the following areas of study:

- Master of Environmental Engineering
- Master of Science in Environmental Engineering and Science (Online)
- Master of Science in Environmental Planning and Management (Online)
- Advanced Certificate for Post-Master's Study in Climate Change, Energy, and Environmental Sustainability (Online)
- Advanced Certificate for Post-Master's Study in Environmental Engineering
- Advanced Certificate for Post-Master's Study in Environmental Engineering and Science (Online)
- Advanced Certificate for Post-Master's Study in Environmental Planning and Management (Online)
- Graduate Certificate in Environmental Engineering
- Graduate Certificate in Environmental Engineering and Science (Online)
- Graduate Certificate in Environmental Planning and Management (Online)

**Dual-degree Programs**

- Master of Environmental Engineering–Master of Business Administration (The Johns Hopkins University Carey Business School)
- Master of Science in Environmental Engineering and Science (online)–Master of Business Administration (The Johns Hopkins University)
- Master of Science in Environmental Planning and Management (online)–Master of Business Administration (The Johns Hopkins University Carey Business School)
- Graduate Certificate in Environmental Planning and Management (online)–Master of Science in Applied Economics (Johns Hopkins Advanced Academic Programs)

**Master of Environmental Engineering**
This area of study focuses on the design of collection and treatment processes for air, water, wastewater, and solid and hazardous waste, including study of the conceptual principles underlying biological, physical, and chemical treatment.

**Admission Requirements**
Prospective students must hold an Accreditation Board for Engineering and Technology (ABET)–accredited undergraduate degree or demonstrated equivalent in an engineering discipline from a four-year regionally accredited college or university to be considered for the Master of Environmental Engineering degree. Moreover, applicants must meet the following criteria:

1. Grade point average of at least 3.0 on a 4.0 scale in the second half of the undergraduate record or hold graduate degrees in an engineering discipline.
2. Successful completion of calculus sequence through differential equations.
3. Successful completion of a course in fluid mechanics or hydraulics.
4. Successful completion of a course in statistics (recommended).

Applicants with an undergraduate degree in natural sciences may be admitted as provisional students to complete additional undergraduate coursework in engineering fundamentals and design prior to full admission to the program.

**Course Requirements**
Attainment of the Master of Environmental Engineering degree requires completion of 10 one-term courses, including at least four courses at the 575.7xx level or above in the entire Environmental Engineering, Science, and Management program, within five years of enrollment.

At least five of the required 10 courses must be taken in the Master of Environmental Engineering area of study.

Up to five elective courses, subject to prerequisite restrictions, may be taken from any of the three areas of study (Master of Environmental Engineering, Master of Science in Environmental Engineering and Science, or Master of Science in Environmental Planning and Management). Any deviation from these degree requirements, including transfer of courses, and other requisites specified in the student's admission letter will not be approved by the program advisors.

Note: The Principles of Environmental Engineering (575.404) course is required of all degree students in the Environmental Engineering, Science, and Management program who do not possess an undergraduate degree in Environmental Engineering.

**Master of Science in Environmental Engineering and Science**
This area of study stresses the fundamental concepts of physics, chemistry, biology, and geology as applied in the context of environmental issues, with less emphasis on design and management.

**Admission Requirements**
Prospective students must hold an undergraduate degree in either engineering or natural science from a four-year regionally accredited college or university to be considered for the Master of Science in Environmental Engineering and Science degree. Moreover, applicants must meet the following criteria:
1. Grade point average of at least 3.0 on a 4.0 scale in the second half of the undergraduate record or hold graduate degrees in an engineering or a natural science discipline.
2. Successful completion of one year of college-level calculus and a course in differential equations.
3. Successful completion of college-level courses is recommended in physics, chemistry, biology, geology, and statistics.

Course Requirements

Attainment of the Master of Science in Environmental Engineering and Science degree requires completion of 10 one-term courses, including at least four courses at the 575.7xx level or above in the entire Environmental Engineering, Science, and Management program, within five years of enrollment.

At least five of the required 10 courses must be taken in the Master of Science in Environmental Engineering and Science area of study.

Up to five elective courses, subject to prerequisite restrictions, may be taken from any of the three areas of study (Master of Environmental Engineering, Master of Science in Environmental Engineering and Science, or Master of Science in Environmental Planning and Management). Any deviation from these degree requirements, including transfer of courses, and other requisites specified in the student's admission letter will not be approved by the program advisors.

Note: The Principles of Environmental Engineering (575.404) course is required of all degree students in the Environmental Engineering, Science, and Management program who do not possess an undergraduate degree in Environmental Engineering.

Master of Science in Environmental Planning and Management

This specialty emphasizes the relationships between environmental engineering/science and public policy with a focus on decision-making tools and policy analysis, as well as emphasis on the role of economic factors in environmental management and water resources planning. This is a professional non-thesis curriculum that encompasses the analytical and conceptual tools to identify, formulate, and evaluate complex environmental and water resources projects and systems, considering the interdisciplinary aspects of the technical, environmental, economic, social, and financial constraints.

Admission Requirements

Prospective students must hold an undergraduate degree in engineering, natural science, economics, planning, management, or other related discipline from a four-year regionally accredited college or university to be considered for the Master of Science in Environmental Planning and Management degree. Moreover, applicants must meet the following criteria:

1. Grade point average of at least 3.0 on a 4.0 scale in the second half of the undergraduate record or hold graduate degrees in engineering, natural science, economics, planning, management, or other related discipline.
2. Successful completion of one year of college-level calculus.
3. Successful completion of college-level courses is recommended in physics, chemistry, biology, geology, and statistics.

Course Requirements

Attainment of the Master of Science in Environmental Planning and Management degree requires completion of 10 one-term courses, including at least four courses at the 575.7xx level or above in the entire Environmental Engineering, Science, and Management program, within five years of enrollment.

At least five of the required 10 courses must be taken in the Master of Science in Environmental Planning and Management area of study.

Up to five elective courses, subject to prerequisite restrictions, may be taken from any of the three areas of study (Master of Environmental Engineering, Master of Science in Environmental Engineering and Science, or Master of Science in Environmental Planning and Management). Any deviation from these degree requirements, including transfer of courses, and other requisites specified in the student's admission letter will not be approved by the program advisors.

Note: The Principles of Environmental Engineering (575.404) course is required of all degree students in the Environmental Engineering, Science, and Management program who do not possess an undergraduate degree in Environmental Engineering.

Advanced Certificate for Post-Master’s Study in Environmental Engineering, Science, and Management

Admission Requirements

Prospective students should possess a master's degree in environmental engineering, science, management, or similar discipline. The program is intended to add depth and/or breadth in the field of the student's master's degree or one that is closely related.

Course Requirements

This certificate is awarded to students who complete six graduate-level courses beyond the master's degree in an environmental engineering, science, or management discipline. The program is intended to add depth and/or breadth in the discipline of the student's master's degree, or a closely related one. At least three of the required six courses must be at the 575.7xx level or above in the Environmental Engineering, Science, and Management program. All courses must be completed with grades above C, within three years of enrollment. This advanced certificate is also offered fully online. At least three of the six courses must be taken within the designated certificate program field. Students must choose between one of the following three programs:

- Advanced Certificate for Post-Master's Study in Environmental Engineering
Advanced Certificate for Post-Master's Study in Environmental Planning and Management (Online)

After the review of student's academic credentials by the admission committee and admittance to the advanced certificate for post-master's study program, each student is assigned an advisor with whom he or she jointly designs a program tailored to individual educational goals. Any deviation from these degree requirements, including transfer of courses, and other requisites specified in the student's admission letter will not be approved by the program advisors.

Students must complete the advanced certificate within three years of the first enrollment in the program.

Advanced Certificate for Post-Master's Study in Climate Change, Energy, and Environmental Sustainability

As the world's population and technological advances continue to grow, demands for natural resources and energy may lead to irrevocable damage to the earth's physical and ecological systems. EP's Climate Change, Energy, and Environmental Sustainability program helps engineers, scientists, and managers design and implement solutions to these environmental challenges. The program provides students with the expertise needed to enter or advance in public and private sectors related to energy, sustainability, and climate. Students gain advanced knowledge in areas such as climate change, energy planning, alternative energy technologies, sustainable development, next-generation buildings, air resources management, and pollution control technologies. Specially designed for working professionals, classes are held on weekday evenings and Saturdays at the Washington, DC, Center near Dupont Circle and at the Montgomery County Campus in Rockville, the Applied Physics Laboratory in Laurel, the Dorsey Center in Elkridge, and the Homewood Campus in Baltimore, Maryland. This advanced certificate is also offered fully online.

Admission Requirements
Prospective students should possess a master's degree in environmental engineering, science, management, or similar discipline. The program is intended to add depth and/or breadth in the field of the student's master's degree or one that is closely related.

Course Requirements
The advanced certificate is awarded to students who complete six graduate-level courses beyond their master's degree. After being admitted to the program, students are assigned an advisor with whom they jointly design a program tailored to their educational goals. Any deviation from these degree requirements, including transfer of courses, and other requisites specified in the student's admission letter will not be approved by the program advisors.

The program consists of five core courses and several advanced electives. If warranted, some of the core courses may be replaced by elective courses. At least three of the required six courses must be at the 575.7xx level or above, with students completing all courses with a grade above C, within three years of enrollment.

Core Courses
- 575.711 Climate Change and Global Environmental Sustainability
- 575.720 Air Resources Modeling and Management
- 575.723 Sustainable Development and Next-Generation Buildings
- 575.733 Energy Planning and the Environment
- 575.734 Smart Growth Strategies for Sustainable Urban Development and Revitalization

Note: All courses within this core are also available online.

Elective Courses
- 575.408 Optimization Methods for Public Decision Making
- 575.411 Economic Foundations for Public Decision Making
- 575.423 Industrial Processes and Pollution Prevention
- 575.435 Environmental Law for Engineers and Scientists
- 575.437 Environmental Impact Assessment
- 575.710 Financing Environmental Projects
- 575.721 Air Quality Control Technologies
- 575.759 Environmental Policy Analysis
- 575.801 Independent Project in Environmental Engineering, Science, and Management
- 615.448 Alternate Energy Technology
- 615.775 Physics of Climate

Note: 575.408, 575.411, 575.423, 575.435, 575.437, 575.710, and 575.759 are also available online.

Graduate Certificate
The graduate certificate is directed toward students who may not need a master's degree, may not have the opportunity to pursue the entire master's degree, or may wish to focus their studies to a set of courses in a specific subject area. Students may wish to pursue one of the following three graduate certificate areas of study:
- Graduate Certificate in Environmental Engineering
- Graduate Certificate in Environmental Engineering and Science (Online)
- Graduate Certificate in Environmental Planning and Management (Online)

The certificate consists of six courses. All grades for the six courses must be above C. If, in the future, the student decides to pursue the full master's degree, all courses will apply provided they meet the program requirements and fall within the
five-year limit, and the student declares her/his intention prior to award of the certificate.

Students must meet the master’s degree admission requirements of the desired area of study. After the review of student’s academic credentials by the admission committee and admittance to the graduate certificate program, each student is assigned an advisor with whom he or she jointly designs a program tailored to individual educational goal. Any deviation from these degree requirements, including transfer of courses, and other requisites specified in the student’s admission letter will not be approved by the program advisors.

Students must complete the graduate certificate within three years of the first enrollment in the program.

**Dual-Degree Environmental–MBA Programs with The Johns Hopkins University Carey Business School**

The need for closer ties between engineering and business management is increasing rapidly. This is demonstrated by the high percentage of students with engineering backgrounds registered in prominent MBA programs nationally.

The Whiting School of Engineering, through Johns Hopkins Engineering for Professionals (EP), and the Carey Business School offer a dual-degree program in which students are admitted to the MS in Environmental Planning and Management, the MS in Environmental Engineering and Science, or the Master of Environmental Engineering within EP and the Professional (Flexible) MBA program within the Carey Business School, either simultaneously or sequentially, and receive two separate degrees, one from each school, in a shorter period than normal because of double counting courses in the two programs.

Students must successfully complete the requirements for both degrees in order to be awarded the two degrees. For the EP degree, students will be able to count two EP course equivalents of academic credit from their Carey MBA toward their 10-course EP degree requirements. For the MBA degree, students will be able to count the academic equivalent of 12 credits from their EP program toward the Carey 54-credit Professional MBA program and, as a result, complete the MBA with 42 credits. Students will attain the two degrees by completing 66 credits (28 courses) rather than 84 credits (36 courses) that would otherwise be required when pursuing these two programs independently.

Both EP and Carey will provide advisor support for students in the dual-degree program. Students enrolled in a course must meet the academic standards of the school offering the course. Failure to meet academic standards of either school could result in probation or dismissal from the particular school.

For additional information about the Professional (Flexible) MBA program at the Carey Business School, please visit the Carey website at carey.jhu.edu.

**Admission Requirements**

Students applying to the dual-degree programs must satisfy the admission requirements of both programs. Each program decides on admissions separately. Students will download the application and submit supporting documents and the application fee to JHU Engineering for Professionals. The application will subsequently be forwarded to JHU Carey Business School.

Students will use EP (the Whiting School of Engineering) as their home school of registration for the duration of the dual degree. Students will register for courses in both schools following the EP registration process.

**Master of Environmental Engineering–Master of Business Administration**

**Course Requirements**

Attainment of this dual degree requires completion of total of 66 credits (28 courses), of which eight courses (24 credits) are from EP’s Environmental Engineering, Science, and Management program and 20 courses (42 credits) are from the MBA Program at the Carey Business School.

Accomplishment of the Master of Environmental Engineering degree component of this dual-degree program requires the completion of a total of eight one-term courses, including at least four courses at the 575.7xx level or above in the Environmental Engineering, Science, and Management program. At least five of the required eight courses must be taken in the Master of Environmental Engineering area of study. Up to three elective courses, subject to prerequisite restrictions, may be taken from any of the three areas of the EP Environmental program (Master of Environmental Engineering, Master of Science in Environmental Engineering and Science, or Master of Science in Environmental Planning and Management). Any deviation from these degree requirements, including transfer of courses from other programs, and other requisites specified in the student’s admission letter will not be approved by the program advisors.

Note: The Principles of Environmental Engineering (575.404) course is required of all degree students in the Environmental Engineering, Science, and Management program who do not possess an undergraduate degree in Environmental Engineering.

For the requirements of the MBA component of this dual-degree program, please visit the Carey Business School website at carey.jhu.edu.

**Master of Science in Environmental Engineering and Science–Master of Business Administration**

**Course Requirements**

Attainment of this dual degree requires completion of total of 66 credits (28 courses), of which eight courses (24 credits) are from EP’s Environmental Engineering, Science, and Management program and 20 courses (42 credits) are from the MBA Program at the Carey Business School.

Accomplishment of the Master of Science in Environmental Engineering and Science degree component of this dual-degree program requires the completion of a total of eight one-term courses, including at least four courses at the
For the requirements of the MBA component of this dual-degree program, please visit the Carey Business School website at carey.jhu.edu.

**Dual-Degree Program with The Johns Hopkins University Zanvyl Krieger School of Arts and Sciences Advanced Academic Programs**

**Master of Science in Applied Economics and Graduate Certificate in Environmental Planning and Management**

To enable professionals to advance in fields that require expertise in both economics and the environment, EP has collaborated with Johns Hopkins Advanced Academic Programs (AAP) to offer a dual program that combines curriculum from the AAP Applied Economics program with EP's Environmental Planning and Management program. Students can earn a Master of Science in Applied Economics and a Graduate Certificate in Environmental Planning and Management by completing 14 courses rather than the 16 courses that would otherwise be required when pursuing these two programs independently. The courses toward the Graduate Certificate in Environmental Planning and Management may be completed online, and the courses toward the MS Degree in Applied Economics are offered in Washington, DC, near Dupont Circle. The course schedule is designed so that working professionals may complete the dual program on a part-time basis, while also allowing students to complete the program at a faster pace. For additional information about AAP's MS in Applied Economics program, please visit AAP's website at advanced.jhu.edu.

**Admission Requirements**

Students applying to the dual-degree program must satisfy the admission requirements of both programs. Each program decides on admissions separately. Students will download the application and submit supporting documents and the application fee to Advanced Academic Programs. The application will be forwarded to JHU Engineering for Professionals.

Students must meet the master's degree admission requirements of the EP's Environmental Planning and Management Program. After the review of student's academic credentials by the admissions committee and Program Chair, both EP and AAP's Applied Economics program will provide advisor support for students in the dual-degree program with whom he or she jointly designs a program tailored to an individual educational goal.

**Course Requirements**

Attainment of this dual degree requires completion of a total of 66 credits (28 courses), of which eight courses (24 credits) are from EP's Environmental Engineering, Science, and Management program and 20 courses (42 credits) are from the MBA Program at the Carey Business School.

Accomplishment of the Master of Science in Environmental Planning and Management degree component of this dual-degree program requires the completion of a total of eight one-term courses, including at least four courses at the 575.7xx level or above in the Environmental Engineering, Science, and Management program. At least five of the required eight courses must be taken in the Master of Science in Environmental Planning and Management area of study. Up to three elective courses, subject to prerequisite restrictions, may be taken from any of the three areas of the EP Environmental Program (Master of Environmental Engineering, Master of Science in Environmental Engineering and Science, or Master of Science in Environmental Planning and Management). Any deviation from these degree requirements, including transfer of courses from other programs, and other requisites specified in the student's admission letter will not be approved by the program advisors.

Note: The Principles of Environmental Engineering (575.404) course is required of all degree students in the Environmental Engineering, Science, and Management program who do not possess an undergraduate degree in Environmental Engineering.
particular school. Students must successfully complete the requirements for both degrees in order to be awarded the two degrees. Any deviation from these degree requirements, including transfer of courses from other programs, and other requisites specified in the student's admission letter will not be approved by the program advisors.

Program Plan
Students are assigned an advisor when accepted. In addition, students are strongly encouraged to contact their advisor prior to registration. Logging of course information as well as viewing of approvals and exceptions permitted by the student's advisor can be tracked through Degree Audit viewable through ISIS.

Special Students
Students who satisfy the admission requirements but do not wish to receive a degree or certificate may also apply to be designated as Special Students to take graduate-level courses for which they have satisfied the relevant prerequisites. If the student is subsequently accepted to a degree or certificate program, the admissions committee will determine whether these courses may be counted in fulfillment of degree requirements.

Course Offerings
Courses are offered at Homewood campus in Baltimore, Montgomery County Campus in Rockville, Dorsey Center in Elkridge, Applied Physics Laboratory in Laurel, Washington, DC, Center, and online.

Note that some of the courses have prerequisites. Students should refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

Classified by the area of study, the courses offered include:

Master of Environmental Engineering
575.401 Fluid Mechanics
575.415 Ecology
575.419 Principles of Toxicology, Risk Assessment, and Management
575.426 Hydrogeology
575.429 Modeling Contaminant Migration through Multimedia Systems
575.443 Aquatic Chemistry
575.445 Environmental Microbiology
575.704 Applied Statistical Analyses and Design of Experiments for Environmental Applications
575.708 Open Channel Hydraulics
575.713 Field Methods in Habitat Analysis and Wetland Delineation
575.716 Principles of Estuarine Environment: The Chesapeake Bay Science and Management
575.717 Hydrology
575.720 Air Resources Modeling and Management
575.727 Environmental Monitoring and Sampling
575.728 Sediment Transport and River Mechanics
575.730 Geomorphic and Ecologic Foundations of Stream Restoration
575.743 Atmospheric Chemistry
575.744 Environmental Chemistry
575.801 Independent Project in Environmental Engineering, Science, and Management

Note: 575.404, 575.405, 575.420, 575.423, 575.703, 575.706, 575.715, 575.721, 575.742, 575.745, and 575.746 are also available online.

Master of Science in Environmental Engineering and Science
575.401 Fluid Mechanics
575.415 Ecology
575.419 Principles of Toxicology, Risk Assessment, and Management
575.426 Hydrogeology
575.429 Modeling Contaminant Migration through Multimedia Systems
575.443 Aquatic Chemistry
575.445 Environmental Microbiology
575.704 Applied Statistical Analyses and Design of Experiments for Environmental Applications
575.708 Open Channel Hydraulics
575.713 Field Methods in Habitat Analysis and Wetland Delineation
575.716 Principles of Estuarine Environment: The Chesapeake Bay Science and Management
575.717 Hydrology
575.720 Air Resources Modeling and Management
575.727 Environmental Monitoring and Sampling
575.728 Sediment Transport and River Mechanics
575.730 Geomorphic and Ecologic Foundations of Stream Restoration
575.743 Atmospheric Chemistry
575.744 Environmental Chemistry
575.801 Independent Project in Environmental Engineering, Science, and Management

Note: 575.401, 575.415, 575.419, 575.426, 575.443, 575.445, 575.704, 575.708, 575.717, 575.720, 575.730, and 575.744 are also available online.

Master of Science in Environmental Planning and Management
575.408 Optimization Methods for Public Decision Making
575.411 Economic Foundations for Public Decision Making
575.416 Engineering Risk and Decision Analysis
575.428 Business Law for Engineers
575.435 Environmental Law for Engineers and Scientists
575.437 Environmental Impact Assessment
575.440 Geographic Information Systems (GIS) and Remote Sensing for Environmental Applications
575.401  Fluid Mechanics
This course introduces the principles of continuity, momentum, and energy applied to fluid motion. Topics include hydrostatics; ideal-fluid flow; laminar flow; turbulent flow; form and surface resistance with applications to fluid measurement; and flow in conduits and channels, pumps, and turbines.

Instructor: Haq
When Offered: Spring
Online Option Available

575.404  Principles of Environmental Engineering
This course addresses the wide range of environmental engineering fundamentals with quantitative analyses where applicable. Topics include mass and energy transfer and balances; environmental chemistry; mathematics of growth and decay; risk assessment and management; surface water pollutants, biological and chemical oxygen demands; eutrophication; water supply systems and drinking water standards; wastewater treatment systems and effluent standards; groundwater flow, contaminant transport, and remediation technologies; hazardous waste and pollution prevention; remedial and corrective actions at contaminated sites; air pollution sources, control technologies, and atmospheric stability; ambient air quality standards and indoor air quality; global temperature, greenhouse effect, and warming potential; global energy balance, carbon emission, and stratospheric ozone depletion; solid waste management, landfill disposal, combustion, composting, and recycling; medical waste; and environmental law, ethics, and justice. Field trips are integrated into the classes.

Prerequisites
This course is required of all degree students in the Environmental Engineering, Science, and Management program who do not possess an undergraduate degree in Environmental Engineering.

Instructors: Alavi, Overcash, Kim
When Offered: Summer
Online Option Available

575.405  Principles of Water and Wastewater Treatment
Water quality objectives and the chemical, physical, and biological processes necessary for designing and managing modern drinking water and wastewater treatment plants are described in the course. The principles of coagulation, flocculation, sedimentation, filtration, biological treatment, solids handling, disinfection, and advanced treatment processes are presented. The course serves as a basis for the more advanced courses: 575.745 Physical and Chemical Processes for Water and Wastewater Treatment, 575.706 Biological Processes for Water and Wastewater Treatment, and 575.746 Water and Wastewater Treatment Plant Design.

Prerequisites
Fluid Mechanics or an equivalent course in fluid flow or hydraulics; two semesters of undergraduate chemistry.

Instructors: Davies-Venn, Movahed
When Offered: Spring
Online Option Available

575.406  Water Supply and Wastewater Collection
This course covers the design of reservoirs, conduits, water distribution systems, well fields, sewers, and drains. Included is a study of population growth and its effects on water supply requirements and sewage flows as well as techniques for analyzing rainfall, runoff, fluid flow, reservoir siting, and groundwater flows.

Prerequisite
575.403 Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

Instructor: Shin
When Offered: Fall

575.407  Radioactive Waste Management
This course covers fundamental aspects of radioactive substances in the environment; remediation processes for these substances; and their eventual storage, processing, and disposal. It provides a basic understanding of radioactivity and its effect on humans and their environment, and the techniques
for their remediation and disposal. Topics include radioactivity, the nucleoids, interaction of radiation with matter, shielding, dosimetry, biological effects, protection standards, sources of environmental radiation, risk evaluation, fate and transport analysis, cleanup standards, legal requirements, cleanup technologies, waste disposal, and case studies.

**Instructor:** Lightner  
**When Offered:** Fall

575.408 *Optimization Methods for Public Decision Making*

This course is an introduction to operations research as applied in the public sector. Public sector operation research involves the development and application of quantitative models and methods intended to help decision makers solve complex environmental and socio-economic problems. The course material is motivated by real-world problems and is presented in an environmental engineering-relevant context. Such problems include air pollution control, water resources management, transportation planning, scheduling, resource allocation, facility location, and biological conservation. Emphasis is placed on skill development in the definition of problems, the formulation of models, and the application of solution methodologies. Methodologies covered in this course include linear programming, integer programming, multi-objective optimization, and dynamic programming.

**Instructor:** Williams  
**When Offered:** Summer  
Online Option Available

575.411 *Economic Foundations for Public Decision Making*

The course examines intermediate-level price theory and surveys applications to public sector decision making. Topics include demand, supply, behavior of the market, and introductory welfare economics. Applications include forecasting, benefit-cost analysis, input-output analysis, and economic modeling.

**Instructor:** Boland  
**When Offered:** Spring  
Online Option Available

575.415 *Ecology*

Course topics include an introduction to the organization of individual organisms into populations, communities, and ecosystems; interactions between individual organisms, groups of organisms, and the environment (including competition, natural selection, adaptation, diversity, and the role of climate change on migration and extinction); the effect of acidification of the environment (including deforestation); and other human impacts on species diversity, community structure, and ecosystem stability.

**Instructor:** Hillgartner  
**When Offered:** Fall  
Online Option Available

575.416 *Engineering Risk and Decision Analysis*

This course introduces students to the methods of risk analysis and decision analysis for engineers. Both quantitative and qualitative risk analysis methods will be covered. Topics will include qualitative risk analysis methods (risk lists; matrices; failure modes and effects analysis; failure modes, effects, and criticality analysis, etc.), quantitative engineering risk analysis methods (fault trees, event trees, etc.), environmental health risk analysis methods, decision bases, the axioms underlying decision analysis, and quantitative decision analysis methods (decision trees, utility functions, risk attitude, value of information calculations, etc.). The course also covers risk perception, risk communication, and risk governance. Expert assessment and the role of cognitive biases in the expert assessment process are included as well. The focus of this course is on the fundamentals of risk and decision analysis rather than their application in a particular field. Examples will be provided on a variety of different fields of engineering, including space system design, environmental management, nuclear stockpile reliability, groundwater cleanup, and electric power system reliability assessment.

**Instructor:** Guikema  
**When Offered:** Fall  
Online Option Available

575.419 *Principles of Toxicology, Risk Assessment, and Management*

Risk assessment and risk management have become central tools in continued efforts to improve public safety and the environment within the limited resources available. This course introduces the basic concepts of environmental risk assessment, relative risk analysis, and risk perception, including identifying and quantifying human health impacts and evaluating ecological risk. The course describes legislative and regulatory initiatives that are attempting to base decisions on risk assessment, along with the controversy that surrounds such approaches. It also addresses specific federal requirements for risk analysis by industry. The course discusses the realities of using risk assessments in risk management decisions, including the need to balance costs and benefits of risk reduction, issues of environmental equity, accounting for the uncertainties in risk estimates, effective risk communication, and acceptable risk.

**Instructor:** Dellarco  
**When Offered:** Fall  
Online Option Available
575.420  Solid Waste Engineering and Management
This course covers engineering and scientific concepts and principles applied to the management of municipal solid waste (MSW) to protect human health and the environment and the conservation of limited resources through resource recovery and recycling of waste material. Topics include regulatory aspects and hierarchy of integrated solid waste management; characterization and properties of MSW; municipal wastewater sludge utilization; hazardous waste found in MSW; collection, transfer, and transport of solid waste; separation, processing, combustion, composting, and recycling of waste material; and the landfill method of solid waste disposal, which encompasses guidelines for design, construction, operation, siting, monitoring, remedial actions, and closure of landfills. Permitting and public participation processes, current issues, and innovative approaches are also addressed.
Instructor: Alavi, Overcash, Kim
When Offered: Fall
Online Option Available

575.423  Industrial Processes and Pollution Prevention
This course presents the pollution prevention and waste minimization concepts, terminologies, life cycle impacts, and management strategies. The course introduces available remediation techniques for industrial pollution control and prevention and examines specific applications to industries including biological, chemical, physical, and thermal techniques. Topics include current state of knowledge of pollution prevention approaches to encourage pollution prevention strategies, highlights of selected clean technologies and clean products, technical and economic issues, incentives and barriers to pollution prevention, and the role of different sectors in promoting pollution prevention. Pollution prevention and waste minimization techniques such as waste reduction, chemical substitution, production process modification, and reuse and recycling will be addressed with regard to selected industries such as textiles, electroplating, pulp and paper, and petroleum refining.
Instructor: Engel-Cox
When Offered: Fall
Online Option Available

575.426  Hydrogeology
This course is an introduction to groundwater and geology and to the interactions between the two. It provides a basic understanding of geologic concepts and processes, focusing on understanding the formation and characteristics of water-bearing formations. The course also addresses the theory of groundwater flow, the hydrology of aquifers, well hydraulics, groundwater-resource evaluation, and groundwater chemistry. The relationship between the geologic concepts/processes and the groundwater resource are discussed. Examples include a discussion of the influence of the geologic environment on the availability and movement of groundwater and on the fate and transport of groundwater contaminants. Geotechnical engineering problems associated with groundwater issues are also covered.
Instructor: Staff
When Offered: Fall
Online Option Available

575.428  Business Law for Engineers
This course introduces engineers to the basic legal principles they will encounter throughout their careers. Course discussions cover contracts (formation, performance, breach, and termination), corporations and partnerships, insurance, professional liability, risk management, environmental law, torts, property law, and evidence and dispute resolution. The course emphasizes those principles necessary to provide engineers with the ability to recognize issues that are likely to arise in the engineering profession and introduces them to the complexities and vagaries of the legal profession.
Instructor: Leiman
When Offered: Fall

575.429  Modeling Contaminant Migration through Multimedia Systems
This course addresses contamination that can affect many media as it migrates through the environment. Typically, contaminant sources occur in soil, from which the chemicals then migrate to air, surface water, and groundwater. Predicting the movement of contaminants through these media requires addressing the fate and transport processes that predominate in each medium and integrating the interactions between the media. The course presents the basic principles and numerical methods for simulation contaminant migration from soil into and through surface-water bodies, air, and groundwater. The basic processes of fate and transport in the various media will be addressed: entrainment, adsorption, volatilization, chemical reactions such as degradation and photolysis, convection, and Gaussian dispersion and deposition. Selected public-domain numerical models will be used to simulate the fate and transport processes. Central to the course will be a project that integrates multimedia environmental modeling through a case study.
Instructors: Robert, Root, Stoddard
When Offered: Summer

575.435  Environmental Law for Engineers and Scientists
This course explores fundamental legal concepts relevant to environmental issues, including the relationship between statutes, regulations, and court decisions. Also included are various forms of enforcement used in environmental rules: command and control, liability, and information disclosure. Specific issues include criminal enforcement, a survey of environmental statutes, regulations and case law, the purpose and
misconceptions surrounding environmental audits and assessments, the concept of attorney-client privilege, unauthorized practice of law, and ethical conflicts between the attorney and engineer/scientist roles.

Instructors: Henderson, Gorski
When Offered: Fall
Online Option Available

575.437 Environmental Impact Assessment
This course examines principles, procedures, methods, and applications of environmental impact assessment. The goal of the course is to promote an understanding of how environmental impact assessment is conducted and used as a valuable tool in the engineering project management decision-making process. Topics include an overview of environmental impact assessment; selection of scientific, engineering, and socioeconomic factors in environmental impact assessment; identification of quantitative and qualitative environmental evaluation criteria; application of traditional and other techniques for assessing impacts of predicted changes in environmental quality; approaches for identifying, measuring, predicting, and mitigating environmental impacts; modeling techniques employed in environmental impact assessment; environmental standards and the environmental impact assessment process; and methodologies for incorporating environmental impact assessment into management decision making. Students learn to prepare an environmental impact assessment, review and critically analyze an environmental impact statement, use mathematical models for environmental impact prediction, and apply environmental impact assessment as a tool in management decision making. Case studies of environmental impact assessment for several types of engineering projects are employed.
Instructor: Toussaint
When Offered: Spring
Online Option Available

575.440 Geographic Information Systems (GIS) and Remote Sensing for Environmental Applications
Through lectures and laboratory exercises, this course illustrates the fundamental concepts of GIS and remote sensing technologies in the context of environmental engineering. Topics include the physical basis for remote sensing, remote sensing systems, digital image processing, data structures, database design, and spatial data analysis. The course is not intended to provide students with extensive training in particular image processing or GIS packages. However, hands-on computer laboratory sessions re-enforce critical concepts. Working knowledge of personal computers and completion of a term project are required.
Instructor: Roper
When Offered: Spring
Online Option Available

575.443 Aquatic Chemistry
Thermodynamics and equilibrium are applied to processes in natural waters, water supply systems, wastewater treatment systems, and other water-based systems. Topics include the chemistry of electrolyte solutions, acids and bases, dissolved carbonate and other pH-buffering solutes, the precipitation and dissolution of inorganic solids, complex formation and chelation, and oxidation-reduction reactions. Quantitative problem solving and the visualization of chemical speciation are emphasized.
Instructor: Gilbert
When Offered: Summer
Online Option Available

575.445 Environmental Microbiology
This course covers fundamental aspects of microbial physiology and ecology. Specific areas of focus include energetics and yield, enzyme and growth kinetics, cell structure and physiology, metabolic and genetic regulation, microbial/environmental interactions, and biogeochemical cycles. The goal of this course is to provide a basic understanding and appreciation of microbial processes that may be applicable to environmental biotechnology.
Instructor: Wilson-Durant
When Offered: Summer (Odd Years)
Online Option Available

575.703 Environmental Biotechnology
This course examines current applications of biotechnology to environmental quality evaluation, monitoring, and remediation of contaminated environments. The scale of technology ranges from the molecular to macrobiotic. Relevant topics of microbiology and plant biology are presented. These provide a foundation for subsequent discussions of microbial removal and degradation of organics, phytoremediation of soil and water contaminated with toxic metals and radionuclides, wetlands as treatment processes, biofilms/biofilters for vapor-phase wastes, and composting. Emphasis is placed on modeling and design. Advantages and disadvantages of each application are compared. Case studies are presented in the areas of biosensors in environmental analysis, molecular biology applications in environmental engineering, and genetic engineering of organisms for bioremediation.
Prerequisite
Prior course work in environmental microbiology or biochemical engineering is recommended but not required.
Instructor: Wilson-Durant
When Offered: Summer (Even Years)
Online Option Available
575.704  Applied Statistical Analyses and Design of Experiments for Environmental Applications
This course introduces statistical analyses and techniques of experimental design appropriate for use in environmental applications. The methods taught in this course allow the experimenter to discriminate between real effects and experimental error in systems that are inherently noisy. Statistically designed experimental programs typically test many variables simultaneously and are very efficient tools for developing empirical mathematical models that accurately describe physical and chemical processes. They are readily applied to production plant, pilot plant, and laboratory systems. Topics covered include fundamental statistics; the statistical basis for recognizing real effects in noisy data; statistical tests and reference distributions; analysis of variance; construction, application, and analysis of factorial and fractional-factorial designs; screening designs; response surface and optimization methods; and applications to pilot plant and waste treatment operations. Particular emphasis is placed on analysis of variance, prediction intervals, and control charting for determining statistical significance as currently required by federal regulations for environmental monitoring.
Instructor: Bodt
When Offered: Summer
Online Option Available

575.706  Biological Processes for Water and Wastewater Treatment
This course develops the fundamentals and applications of aerobic and anaerobic biological unit processes for the treatment of municipal and industrial wastewater. The principles of activated sludge, aeration and clarifier design, fixed film reactors, anaerobic treatment, solids handling and treatment, land treatment, and nutrient removal are presented. This course uses concepts from microbiology, and the basic principles of stoichiometry, energetics, and microbial kinetics are used to support the design of biological unit processes.
Prerequisite 575.405 Principles of Water and Wastewater Treatment.
Instructor: Weiss
When Offered: Spring
Online Option Available

575.707  Environmental Compliance Management
The course covers compliance with environmental laws and regulations by industry, small business, government facilities, and others. It includes legal responsibilities, environmental management systems, and practices such as audits and information systems and development of corporate policies and procedures that rise to the daunting challenge to harmonize the institution’s primary goals with its environmental obligations. Several dimensions of environmental management are discussed: federal, state, and local regulation; scientific/technical factors; public relations and the press; and institutional objectives including economic competitiveness.
Instructor: Riegel
When Offered: Spring
Online Option Available

575.708  Open Channel Hydraulics
The course covers application of the principles of fluid mechanics to flow in open channels. Topics include uniform flow, flow resistance, gradually varied flow, flow transitions, and unsteady flow. The course also addresses flow in irregular and compound channels, backwater and 2D flow modeling, and applications to channel design and stability.
Prerequisite Fluid Mechanics or an equivalent course in fluid flow or hydraulics.
Instructor: Hudson
When Offered: Summer
Online Option Available

575.710  Financing Environmental Projects
This course treats the financing of projects from two complementary perspectives: that of a government agency funding source and that of an environmental utility (water, wastewater, solid waste) that needs funds for its project. It discusses grants, concessionary loans, market loans, and loan guarantees, along with their relative desirability and efficiency. Since grant funding is never available for all projects, the course deals extensively with borrowing/lending. It discusses strategies for maximizing utility income, including appropriate tariff structures and the reform of government subsidy policy from supply-based general subsidies to demand-based targeted subsidies. Operational strategies to maximize income are also discussed, such as techniques to improve billing and collections, reduce losses, and reduce energy costs. Traditional cash flow analyses are used to determine debt service capabilities. Various project cost reduction strategies, such as staging and scaling, are introduced. Grants in the form of upfront project cost buy-downs vs. annual debt service subsidies are compared. Finally, several examples of project financings combining many of the elements introduced during the course are presented and analyzed.
Instructor: Tucker
When Offered: Summer

575.711  Climate Change and Global Environmental Sustainability
This is a multidisciplinary course that focuses on the critical assessment of science, impacts, mitigation, adaptation, and policy relevant to climate change and global environmental sustainability. The first half of the course actively investigates concepts and aspects of environmental sustainability, including the review of international assessments and reports and the analyses of relevant implications for human health, natural resources, energy supply and demand, and waste/pollution.
The second half of the class addresses climate change science; existing evidence and observations of climate change; models and predictions of potential physical, ecological, and anthropological impacts; technological, economic, political, and consumer driven mitigation and adaptation strategies; and past and present local, state, federal, and international policy and legislation. This course stresses active learning and critical thinking. It requires both the objective and subjective analyses of an array of environmental sustainability and climate change topics and materials. Students will be required to report on a current work of relevant nonfiction in the field, complete an original case study, and critically review climate change documentaries. Students will also be required to complete quantitative technical assignments; research popular press, governmental agency, and peer-reviewed scientific literature; and participate in class discussions, presentations, and exercises.

**Instructor:** Robert  
**When Offered:** Spring  
Online Option Available

**575.713 Field Methods in Habitat Analysis and Wetland Delineation**

The course provides students with practical field experience in the collection and analysis of field data needed for wetland delineation, habitat restoration, and description of vegetation communities. Among the course topics are sampling techniques for describing plant species distributions and community structure and diversity, including the quadrant and transect-based, point-intercept, and plotless methods; identification of common and dominant indicator plant species of wetlands and uplands; identification of hydric soils; use of soil, topographic, and geologic maps and aerial photographs in deriving a site description and site history; and graphic and statistical methods including GIS applications for analyzing and presenting the field data. The classes consist of field studies at regional and local sites.

**Prerequisite**  
575.415 Ecology.

**Instructor:** Hilgartner  
**When Offered:** Summer

**575.714 Water Resources Management**

This course examines watershed approaches to maintenance of the hydrological, chemical, and biological integrity of the nation’s waters. Water supply topics include rainfall runoff relationships, probabilistic flow analysis, multiple-objective reservoir siting and operation, and safe yield analysis. Water quality topics include regulatory requirements; non-point source runoff; point source discharge; water quality analysis of streams, lakes, and estuaries (including waste heat, conventional pollutants, and toxic chemicals); and in-stream biological resource requirements and assessment. Both the water supply and water quality discussions provide an overview of current computer simulation models. The course concludes with new integrated approaches for watershed management, including Waste Load Allocation and Total Maximum Daily Loss (TMDL) analysis for pollutants entering water bodies.

**Instructors:** George, Williams  
**When Offered:** Summer  
Online Option Available

**575.715 Subsurface Fate and Contaminant Transport**

This course provides an introduction to the concepts relating to the nature and sources of environmental contaminants in the subsurface, the role of groundwater and soil water in mobilizing and spreading contamination, the processes that control distribution and fate of subsurface contamination, the accepted methods of investigating and analyzing contamination, and the analytical techniques that can be employed to model contaminant fate and transport in the subsurface. The course also considers surface water contamination caused by contamination in the groundwater. Computer laboratories of groundwater model simulations and solute transport solutions are used.

**Instructor:** Barranco  
**When Offered:** Spring  
Online Option Available

**575.716 Principles of Estuarine Environment: The Chesapeake Bay Science and Management**

The course examines the basic physical, chemical, and biological components of the Chesapeake Bay ecosystem and how they interrelate in both healthy and degraded states of an estuary. The course focuses on the tidal waters of the Chesapeake Bay and its tributaries. It also covers the relationships of the Bay with the surrounding watershed, atmosphere, and ocean as well as relevance to other coastal systems. Particular emphasis is given to anthropogenic stresses such as nutrient and contaminant pollution, habitat modification, and harvest of fish and shellfish. The most current Chesapeake Bay management issues and policies being pursued at the federal, state, and local levels of government are discussed in depth, including their scientific foundation.

**Instructor:** Brush  
**When Offered:** Fall (Odd Years)

**575.717 Hydrology**

This course reviews components of the hydrologic cycle, including precipitation, evapotranspiration, infiltration, subsurface flow, and runoff. Analysis of hydrologic data, including frequency analysis and the use of stochastic models for describing hydrologic processes, is also covered.

**Prerequisite**  
Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

**Instructor:** Raffensperger  
**When Offered:** Spring  
Online Option Available
575.720  Air Resources Modeling and Management
This course is a comprehensive overview of air resources modeling and management. Topics covered in this course include an introduction to particulate matter and gas-phase pollutant chemistry and physics; an overview of atmospheric motion to give students a sense of how air pollutant transport and transformation is modeled; air pollution modeling fundamentals and applications; an assessment of air pollution exposure, health effects, and toxicological and epidemiological considerations; regulatory considerations in air pollution control related to model selection and use; and a brief overview of air pollution control technologies and specific considerations relative to indoor air quality and climate change. Specific air pollution problems addressed in the course include those involving the state of air pollution at local, regional, and national scales; air pollution problems from a public health perspective; and system analytic approaches for developing air pollution control strategies for particulate matter, tropospheric ozone, acid rain, carbon monoxide, nitrogen oxides, and greenhouse gases. A term-long case study assignment is required that will leverage these course elements against a relevant real-world air pollution scenario.
Instructor: Ellis, Robert
When Offered: Fall
Online Option Available

575.721  Air Quality Control Technologies
This is a multidisciplinary course that involves the applications of chemistry, thermodynamics, and fluid mechanics in the selection and design of air pollution control equipment. Topics include the estimation of potential pollutants, chemical characterization of gas streams to be controlled, theory and practice of air pollution control, and design and costing of control technologies. The course emphasizes the design of systems to reduce particulate matter emissions, volatile organic compound (VOC) emissions, nitrogen oxide emissions, and sulfur dioxide emissions.
Prerequisites
Fluid Mechanics or an equivalent course in fluid flow; an undergraduate course in thermodynamics.
Instructor: Roper
When Offered: Summer
Online Option Available

575.723  Sustainable Development and Next-Generation Buildings
The course will introduce the concepts, applications, and tools for analysis and decision making in support of sustainable environmental development and next-generation communities and building design. Students will be introduced to a variety of challenges related to environmental protection, stewardship, and management of air, soil, and water. The underlying principles of ecological protection, stewardship, reduced environmental footprint, ecosystem capital, sustainable economic development, and globalization impacts will be reviewed. The integration of actions that are ecologically viable, economically feasible, and socially desirable to achieve sustainable solutions will be evaluated. Within this context, sustainable building concepts will be explored that are intended to provide throughout their lifetime a beneficial impact on their occupants and their surrounding environment. Such buildings are optimally integrated on all parameters—in initial affordability, timeliness of completion, net life-cycle cost, durability, functionality for programs and persons, health, safety, accessibility, aesthetic and urban design, maintainability, energy efficiency, and environmental sustainability. The principles of LEED building design and certification will also be introduced and example projects reviewed. Integrated design and construction practices that significantly reduce or eliminate the negative impact of buildings on the environment and occupants will be assessed in the broad areas of: (1) sustainable site planning, (2) safeguarding water and water efficiency, (3) energy efficiency and renewable energy, (4) conservation of materials and resources, and (5) indoor environmental quality. A critical element for a successful sustainable building policy and program is an integrated building planning and design process. Integrated planning and design refers to an interactive and collaborative process in which all stakeholders are actively involved and communicate with one another throughout the design and construction practice. These processes will also provide a broader understanding of sustainable options for infrastructure changes that may occur in various BRAC planning and implementation situations. A number of case studies will be examined to gain an understanding of application issues.
Instructor: Stoddard
When Offered: Fall (Odd Years)
575.728  Sediment Transport and River Mechanics
This course examines the processes of sediment entrainment, transport, and deposition and the interaction of flow and transport in shaping river channels. Topics reviewed include boundary layer flow; physical properties of sediment; incipient, bed-load, and suspended-load motion; bed forms; hydraulic roughness; velocity and stress fields in open channels; scour and deposition of bed material; bank erosion; and size, shape, platform, and migration of river channels. In addition, the course develops techniques of laboratory, theoretical, and numerical modeling and applies them to problems of channel design, restoration, and maintenance.

Prerequisite
Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

Instructor: Wilcock
When Offered: Spring (Odd Years)

575.730  Geomorphic and Ecologic Foundations of Stream Restoration
This course presents principles from hydrology, sedimentation engineering, geomorphology, and ecology relevant to the design and evaluation of stream restoration projects. A watershed context is emphasized in developing the background needed to assess different design approaches. After developing a common foundation in stream dynamics, the course considers trade-offs among restoration objectives, the merits of analog and predictive approaches, the role of uncertainty in restoration design, and metrics for assessing ecological recovery. The course includes field trips, design exercises, and project assessment.

Instructors: Wilcock, Baker
When Offered: Spring (Even Years)
Online Option Available

575.731  Water Resources Planning
The course will discuss the application and interrelationships among microeconomics, ecology, hydrology, and related fields to the planning and management of water systems. Topics will include flood control, navigation, hydroelectric power, water supply, environmental restoration, multiobjective planning, and urban water resource management. The course will demonstrate the process for planning a water resource project, including identifying the problems and opportunities, invento- rying and forecasting conditions, formulating alternative plans, evaluating alternative plans, comparing alternative plans, and selecting a plan. Particular attention will be paid to the appropriate interdisciplinary approach to plan formulation.

Instructor: Kranzer
When Offered: Fall
Online Option Available

575.733  Energy Planning and the Environment
This course examines the interrelationships between the environment and the ways in which energy is produced, distributed, and used. Worldwide energy use patterns and projections are reviewed. Particular attention is paid to the electrical and transportation sectors of energy use. Underlying scientific principles are studied to provide a basis for understanding the inevitable environmental consequences of energy use. Topics studied include fossil, nuclear, and existing and potential renewable sources, including hydroelectric, geothermal, tidal, wind, and solar. Transportation options including internal combustion, hybrid, and electric options are quantitatively compared. Use of alternate fuels such as biodiesel and ethanol are evaluated. Emphasis is placed on the environmental impacts of energy sources, including local effects resulting from emissions of nitrogen oxides, sulfur, hydrocarbons, and particulates as well as global effects such as mercury release from coal combustion. Carbon emissions are a continuing theme as each energy technology is studied and its contribution to climate change is assessed. Carbon suppression schemes are examined. Particular attention is paid to consequences and effectiveness of government intervention and regulation. The purpose is to help students understand how energy is converted into useful forms, how this conversion impacts our environment, and how public policy can shape these impacts.

Prerequisite
575.411 Economic Foundations for Public Decision Making, or an equivalent course in microeconomic theory, is recommended.

Instructor: Lightner
When Offered: Summer
Online Option Available

575.734  Smart Growth Strategies for Sustainable Urban Development and Revitalization
This course addresses the concepts, practices, and tools for smart growth sustainable urban planning and provides an understanding for how to apply these to urban communities. The sustainable urban development is a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for future generations to come. In other words, it is the development and restoration of urban areas that will meet the needs of the present without compromising the ability of future generations to meet their own needs. The course addresses a number of urban design concepts for smart growth and sustainable development, including balanced land use planning principles; importance of an overall transportation strategy; providing urban tree coverage; leveraging public transportation accessibility; providing a spectrum of housing availability; integration of office, retail, and housing units; reduction of urban area environmental footprint; use of recycled, reused, reusable, green, and sus- tainable products; integration of renewable solar energy and wind power into buildings and government systems; transit-oriented development; innovative low-impact storm water management practices; reduction in urban heat island effects;
urban water resource management; and energy efficiency and conservation.

Instructor: Roper

When Offered: Fall

Online Option Available

575.735 Energy Policy and Planning Modeling
This course provides students with comprehensive knowledge on methods for optimizing operation and design of energy systems and methods for analyzing market impacts of energy and environmental policies with emphasis on both theory and solution of actual models. The course also covers linear and nonlinear programming and complementarity methods for market simulation.

Prerequisites
575.411 Economic Foundations for Public Decision Making and 575.408 Optimization Methods for Public Decision Making or equivalent courses in intermediate microeconomics and optimization methods (linear programming), or permission of instructor.

Instructor: Hobbs

When Offered: Spring

575.742 Hazardous Waste Engineering and Management
The course addresses traditional and innovative technologies, concepts, and principles applied to the management of hazardous waste and contaminated sites to protect human health and the environment. Topics include regulatory requirements; fate and transport of contaminants; physical, chemical, and biological treatment; land disposal restrictions; guidelines for design, construction, and closure of hazardous waste landfills; environmental monitoring systems; management of medical waste and treatment options; management of underground and aboveground storage tanks; toxicology and risk assessment; pollution prevention and waste minimization; hazardous waste generators and transporters; permitting and enforcement of hazardous waste facilities; closure and financial assurance requirements; and RCRA Subtitle C Corrective Action and CERCLA/Superfund/Brownfields site remediation processes.

Instructors: Alavi, Overcash, Kim

When Offered: Spring

Online Option Available

575.743 Atmospheric Chemistry
Earth’s atmosphere is a vital, fragile component of our environment. This course covers the chemical composition of the atmosphere and the principles of chemistry that control the concentrations of chemical species. Following an introduction to the atmosphere, including its structure and key physical concepts of atmospheric thermodynamics, radiative transfer, and dynamics, the course investigates gas- and aqueous-phase chemical kinetics, molecular spectroscopy, and photochemical processes. This foundation of chemistry and physics is then applied to the study of ozone in the stratosphere (‘good’ ozone) and troposphere (‘bad’ ozone) and the global chemical cycles of sulfur-, nitrogen-, carbon-, and halogen-containing trace constituents, with implications for the environment. In each case, a description of typical in situ and remote sensing measurement techniques is included. Clouds, atmospheric aerosols, and climate change and their interactions with atmospheric chemistry are discussed, and connections between atmospheric chemistry and health, such as through fine particulate matter and ground-level ozone, are also made. The course concludes with a survey of chemistry transport and statistical computer modeling of atmospheric chemistry.

Instructor: Swartz

When Offered: Fall

575.744 Environmental Chemistry
This course focuses on the environmental behavior and fate of anthropogenic contaminants in aquatic environments. Students learn to predict contaminant properties influencing contaminant transfers between hydrophobic phases, air, water, sediments, and biota, based on a fundamental understanding of physico-chemical properties, intermolecular interactions, and basic thermodynamic principles. Mechanisms of important transformation reactions are also discussed and techniques and quantitative models for predicting the environmental fate or human exposure potential of contaminants are discussed.

Instructor: Jayasundera

When Offered: Fall

Online Option Available

575.745 Physical and Chemical Processes for Water and Wastewater Treatment
In this course, mass and momentum transport, aquatic chemistry, and chemical reaction engineering are applied to physical and chemical processes used for water and wastewater treatment. Students also learn the theory and practice of various unit processes including disinfection, oxidation, coagulation, sedimentation, filtration, adsorption, gas transfer, and membrane filtration. The goal is to provide a theoretical understanding of various chemical and physical unit operations, with direct application of these operations to the design and operation of water and wastewater treatment systems. Students will use the concepts learned in this class to better understand the design and operation of engineered and natural aquatic systems.

Prerequisite
575.405 Principles of Water and Wastewater Treatment.

Instructor: Arora

When Offered: Fall

Online Option Available
Companies also use EMS to improve their corporate image, and water pollution caused by a firm’s operations, and (3) water, energy and non-renewable resources, (2) reduce air of a core set of actions designed to (1) reduce the use of engineering profession and private industry. EMS consists constitute the primary environmental interface between the ing in Environmental Management Systems (EMS), which serve as the primary environmental interface between the profession and private industry. EMS consists of a core set of actions designed to (1) reduce the use of water, energy and non-renewable resources, (2) reduce air and water pollution caused by a firm’s operations, and (3) assure compliance with environmental rules and regulations. Companies also use EMS to improve their corporate image, resulting in increasing sales to environmentally conscious customers, attracting investment from Socially Responsible Investment (SRI) Funds, generating favorable public opinion, and improving employee morale.

Topics discussed include “greening the supply chain,” Life Cycle Analysis (LCA), the Leadership in Energy & Environmental Design (LEED) program for buildings, the Energy Star program for energy management, and the ISO 14000 program for environmental certification. The course will also discuss important, but less well-known, EMS strategies like the impact of green roofs on HVAC costs or the impact of water costs from gray water management systems, all of which are well documented by government and other organizations.

**575.747 Environmental Project Management**

This course educates students on the key elements of an integrated approach to environmental project management, an endeavor that requires expertise in scientific, engineering, legal, public policy, and project management disciplines. Emphasis is placed on critical factors that are often unique to a major environmental project, such as the uncertainty surrounding scope definition for environmental cleanup projects and the evolving environmental regulatory environment. The students learn to develop environmental project plans, establish project organization and staffing, define management functions, develop time management approaches, resolve project conflicts, determine project effectiveness, implement integrated project management techniques such as the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM) as they relate to environmental project management, perform pricing and cost estimating, establish cost control, set priorities, and perform tradeoff analyses. The course uses environmental project case studies to examine the integrated nature of environmental project management. Examples of topics to be covered in this case study format include environmental security projects, environmental technology deployment projects, privatization of government environmental projects, and pollution prevention/waste minimization projects.

**Instructor:** Davier-Venn  
**When Offered:** Summer

**575.759 Environmental Policy Analysis**

The course explores the problem of developing appropriate public policies for the primary purpose of restoring, preserving, and protecting aspects of the physical environment. Emphasis is placed on the need to harmonize environmental science, human health, socio-political, technological, legal, financial, and economic considerations in a context of incomplete information and uncertain futures. One or more specific environmental policies are studied in the course of the semester. Students are expected to plan and execute individual research projects that demonstrate the use of quantitative and/or economic tools in designing and evaluating responses to environmental management problems.

**Instructor:** Boland  
**When Offered:** Fall

**575.801 Independent Project in Environmental Engineering, Science, and Management**

This course provides students with an opportunity to carry out a significant project in the field of environmental engineering, science, technology, planning, or management as a part of their graduate program. The project is individually tailored and supervised under the direction of a faculty member and may involve conducting a semester-long research project, an in-depth literature review, a non-laboratory study, or application of a recent development in the field. The student may be required to participate in conferences relevant to the area of study. To enroll in this course, the student must be a graduate candidate in the environmental engineering, science, and management program within the latter half of the degree requirements and must obtain the approval and support of a sponsoring faculty member in the Department of Geography and Environmental Engineering. The proposal description and completed required forms must be submitted prior to registration for approval by the student’s advisor and the program.
chair. A maximum of one independent project course may be applied toward the master’s degree or post-master’s certificate.

Prerequisites
Note: This course must be completed with a member of the faculty of the Department of Geography and Environmental Engineering.

When Offered: All Semesters
Cybersecurity

In today’s world, the need to protect an organization’s information and systems from attack is of critical importance. The goal of cybersecurity is to enhance the security of information and information systems by ensuring availability, integrity, authentication, confidentiality, and non-repudiation. This includes providing for the preservation and restoration of systems by incorporating protection, detection, and reaction capabilities. Cybersecurity also focuses on risk management to address threats to new and existing systems.

The Master of Science in Cybersecurity is designed to appeal to a broad range of individuals. The program balances theory with practice, providing students with the knowledge and skills needed to protect and defend information systems from attack.

Courses are offered in three tracks: systems, networks, and analysis. In the systems area, attacks are explored from within the system boundary with an emphasis on platform, operating systems, and secure software development. The networks area focuses on protecting information assets from network-based intrusions and from attacks that are primarily focused on remote exploitation of protected systems. Cybersecurity approaches that are effective in this paradigm are explored in depth and a variety of defensive approaches are investigated. Analysis contributes to both the systems and networks tracks. Analysis courses study low-level behavior, code, and data to understand anomalies and develop the ability to identify unexpected patterns and malicious events. Courses from all three tracks may be interleaved to satisfy the interests of the student.

Students may take courses at the Applied Physics Laboratory, the Montgomery County Campus, the Dorsey Center, and online. Extensive computing facilities are available and can be reached from any of the sites or from home via high-speed broadband Internet connections. The facilities also support a variety of software systems, applications, development tools, and specialized labs.

Program Committee

Thomas A. Longstaff, Program Chair
Principal Professional Staff
Applied Physics Laboratory

Eleanor Boyle Chlan, Associate Program Chair
Senior Lecturer in Computer Science
Whiting School of Engineering

John A. Piorkowski
Principal Professional Staff
Applied Physics Laboratory

Michael Smeltzer
Senior Professional Staff
Applied Physics Laboratory

J. Miller Whisnant
Principal Professional Staff
Applied Physics Laboratory

Admission Requirements

Applicants must meet the general requirements for admission to a graduate program outlined in the Admission Requirements (page 4) section of the catalog. In addition, applicants must have completed each of the following with a grade of A or B:

A. One year of calculus (two semesters or three quarters)
B. One mathematics course beyond calculus (e.g., discrete mathematics, linear algebra, or differential equations)—one term
C. One year of introductory computer science including a course in Java or C++, and data structures
D. A course in computer organization—one term

Applicants who have not taken the prerequisite undergraduate courses may satisfy admission requirements by completing the specified courses with grades of A or B. The program offers the following undergraduate courses, which may be taken as needed to satisfy the computer science prerequisites and the requirement for a mathematics course beyond calculus.

- 605.201 Introduction to Programming Using Java
- 605.202 Data Structures
- 605.203 Discrete Mathematics
- 605.204 Computer Organization

Advanced Certificate for Post-Master’s Study in Cybersecurity

Applicants who have already completed a master’s degree in a technical discipline are eligible to apply for an Advanced Certificate for Post-Master’s Study in Cybersecurity. Six one-term courses must be completed with grades of A or B. The program offers the following undergraduate courses, which may be taken as needed to satisfy the computer science prerequisites and the requirement for a mathematics course beyond calculus.

- 605.201 Introduction to Programming Using Java
- 605.202 Data Structures
- 605.203 Discrete Mathematics
- 605.204 Computer Organization

Course Requirements for Master’s Degree

Ten courses, approved by an advisor, must be completed within five years. At least eight courses must be from the Cybersecurity curriculum, which includes Cybersecurity courses as well as selected courses from computer science, security informatics, and applied mathematics and statistics. Three courses must be from the same track and at least two of the Cybersecurity courses must be 700 level. No more than one course with a grade of C, and no course with a grade lower than C, may be counted toward the degree.

Students may take up to two electives from outside Cybersecurity. Electives can be selected from computer science, electrical and computer engineering, and applied computational mathematics. Other electives require approval of the Cybersecurity program chair or vice chair. Students who take electives from other programs must meet the specific course and program requirements listed for each course. In the event that the student has transfer courses accepted, they will be considered electives.
Students should have had a course in networking prior to taking concentration courses in the Networks track, a course in operating systems prior to taking courses in the Systems track, and a course in both before taking courses in the Analysis track. If necessary, 605.412 Operating Systems and 605.471 Principles of Data Communications Networks can be taken and applied toward the master's degree in Cybersecurity.

Graduate students not pursuing a master's degree in Cybersecurity should consult with their advisor to determine what courses must be successfully completed before 400- or 700-level Cybersecurity courses may be taken. It should be noted that 700-level courses are open only to students who have been admitted with graduate status.

Please refer to the Course Schedule published each term for dates, times, locations, fees, and instructors.

**Cybersecurity—Online**

Students may complete the Master of Science in Cybersecurity online, and all students may take advantage of online offerings. While not all courses are available online, a complete program is offered and additional online courses are continually being developed. This increases the flexibility of course offerings for students wishing to pursue studies in either the face-to-face or online format, or a combination of both.

Online course content is identical to that in the face-to-face offerings but available in a paced, asynchronous mode over the Internet. Recorded lectures with associated multimedia content are augmented with online discussions and weekly synchronous office hours. Prospective and current students should consult the EP website for the current online course offerings, course schedules, and procedures for online programs.

**Foundation Courses**
The 400-level foundation courses must be taken before other graduate courses, while the 700-level foundation course may be completed anytime after that during the course of the Cybersecurity degree:

- 695.401 Foundations of Information Assurance
- 605.421 Foundations of Algorithms
- 695.701 Cryptology

One or more foundation courses can be waived by the student's advisor if a student has received an A or B in equivalent courses. In this case, the student may replace the waived foundation courses with the same number of other graduate courses and may take these courses after all remaining foundation course requirements have been satisfied.

**Graduate Courses by Track**
The Cybersecurity tracks including all applicable courses from Cybersecurity, Computer Science, and Security Informatics are as follows:

### I. Systems
- 695.401 Foundations of Information Assurance
- 695.411 Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms
- 695.711 Java Security
- 695.712 Authentication Technologies in Cybersecurity
- 695.791 Information Assurance Architectures and Technologies
- 605.401 Foundations of Software Engineering
- 605.412 Operating Systems
- 605.421 Foundations of Algorithms
- 605.704 Object-Oriented Analysis and Design
- 605.715 Software Development for Real-Time Embedded Systems
- 605.716 Modeling and Simulation of Complex Systems

### Systems Courses at Homewood
- 550.471 Cryptography and Coding
- 600.643 Advanced Topics in Computer Security
- 600.648 Secure Software Engineering

### II. Networks
- 695.421 Public Key Infrastructure and Managing E-Security
- 695.422 Web Security
- 695.701 Cryptology
- 695.721 Network Security
- 695.722 Covert Channels
- 695.791 Information Assurance Architectures and Technologies
- 605.471 Principles of Data Communications Networks
- 605.472 Computer Network Architectures and Protocols
- 605.474 Network Programming
- 605.475 Protocol Design and Simulation
- 605.771 Wired and Wireless Local and Metropolitan Area Networks

### Networks Courses at Homewood
- 600.642 Advanced Cryptographic Protocols

### III. Analysis
- 695.442 Intrusion Detection
- 695.443 Introduction to Ethical Hacking
- 695.741 Information Assurance Analysis
- 695.742 Digital Forensics Technologies and Techniques
- 695.744 Reverse Engineering and Vulnerability Analysis

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Cybersecurity

Analysis Courses at Homewood

- 550.438 Statistical Methods for Intrusion Detection
- 650.457 Computer Forensics
- 650.459 Software Vulnerability Analysis

IV. Special Topics

- 695.801 Independent Study in Cybersecurity I
- 695.802 Independent Study in Cybersecurity II

Course Descriptions

695.401 Foundations of Information Assurance
This course surveys the broad fields of enterprise security and privacy, concentrating on the nature of enterprise security requirements by identifying threats to enterprise information technology (IT) systems, access control and open systems, and system and product evaluation criteria. Risk management and policy considerations are examined with respect to the technical nature of enterprise security as represented by government guidance and regulations to support information confidentiality, integrity, and availability. The course develops the student's ability to assess enterprise security risk and to formulate technical recommendations in the areas of hardware and software. Aspects of security-related topics to be discussed include network security, cryptography, IT technology issues, and database security. The course addresses evolving Internet, Intranet, and Extranet security issues that affect enterprise security. Additional topics include access control (hardware and software), communications security, and the proper use of system software (operating system and utilities). The course addresses the social and legal problems of individual privacy in an information processing environment, as well as the computer “crime” potential of such systems. The class examines several data encryption algorithms.

Instructors: Ambuel, Heinbuch, Podell, Tarr

Online Option Available

695.411 Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms
While most of the world is preoccupied with high-profile network-based computer intrusions, this online course examines the potential for computer crime and the protection mechanisms employed in conjunction with the embedded computers that can be found within non-networked products (e.g., vending machines, automotive onboard computers, etc.). This course provides a basic understanding of embedded computer systems: differences with respect to network-based computers, programmability, exploitation methods, and current intrusion protection techniques along with material relating to computer hacking and vulnerability assessment. The course materials consist of a set of eight study modules and five case-study experiments (to be completed at a rate of one per week) and are augmented by online discussion forums moderated by the instructor. This course also includes online discussion forums that support greater depth of understanding of the materials presented within the study modules.

Prerequisites

- 605.412 Operating Systems or basic knowledge of Operating Systems is recommended.

Instructors: Ching, McGuire
605.412 Operating Systems or basic knowledge of Operating Systems is recommended.

Instructors: Ching, McGuire

695.442 Intrusion Detection
Formerly 695.423 Intrusion Detection
This course explores the use of intrusion detection systems (IDS) as part of an organization’s overall security posture. A variety of approaches, models, and algorithms along with the practical concerns of deploying IDS in an enterprise environment will be discussed. Topics include the history of IDS, anomaly and misuse detection for both host and network environments, and policy and legal issues surrounding the use of IDS. The use of ROC (receiver operating characteristic) curves to discuss false positives and missed detection tradeoffs as well as discussion of current research topics will provide a comprehensive understanding of when and how IDS can complement host and network security. TCPDump and Snort will be used in student assignments to collect and analyze potential attacks.

Instructor: Longstaff
Online Option Available

695.443 Introduction to Ethical Hacking
This course exposes students to the world of computer hacking. The primary goal is to give students an understanding of how vulnerable systems can be attacked as a means to motivate how they might be better defended. The class takes a systems engineering view of hacking and emphasizes practical exposure via hands-on assignments. Students are expected to use a computer that will remain off all networks while they complete assignments.

Prerequisites
695.401 Foundations of Information Assurance and 635.411 Principles of Network Engineering or 605.471 Principles of Data Communication Networks, or equivalent experience.

Course Notes
Homework assignments will include programming.

Instructors: Llanso, Smeltzer

695.701 Cryptology
This course provides an introduction to the principles and practice of contemporary cryptology. It begins with a brief survey of classical cryptographic techniques that influenced the modern development of cryptology. The course then focuses on contemporary work: symmetric block ciphers and the Advanced Encryption Standard, public key cryptosystems, digital signatures, authentication protocols, and cryptographic hash functions. Pertinent ideas from complexity theory and computational number theory, which provide the foundation for much of the contemporary work in cryptology, are introduced, as needed, throughout the course.

Instructor: May, Zaret
Online Option Available

695.711 Java Security
This course examines security topics in the context of the Java language with emphasis on security services such as confidentiality, integrity, authentication, access control, and non-repudiation. Specific topics include mobile code, mechanisms for building “sandboxes” (e.g., class loaders, namespaces, bytecode verification, access controllers, protection domains, policy files), symmetric and asymmetric data encryption, hashing, digital certificates, signature and MAC generation/verification, code signing, key management, SSL, and object-level protection. Various supporting APIs are also considered, including the Java Cryptography Architecture (JCA) and Java Cryptography Extension (JCE). Security APIs for XML and web services, such as XML Signature and XML Encryption, Security Assertions Markup Language (SAML), and Extensible Access Control Markup Language (XACML), are also surveyed. The course includes multiple programming assignments and a project.

Prerequisites
605.481 Principles of Enterprise Web Development or equivalent. Basic knowledge of XML. 695.401 Foundations of Information Assurance or 695.422 Web Security would be helpful but is not required.

Instructors: Ceesay, Llanso

695.712 Authentication Technologies in Cybersecurity
Authentication technologies in cybersecurity play an important role in identification, authentication, authorization, and non-repudiation of an entity. The authentication process in cybersecurity, which is considered to be one of the weakest links in computer security today, takes many forms as new technologies such as cloud computing, mobile devices, biometrics, PKI, and wireless are implemented. Authentication is the security process that validates the claimed identity of an entity, relying on one or more characteristics bound to that entity. An entity can be, but is not limited to, software, firmware, physical devices, and humans. The course explores the underlying technology, the role of multi-factor authentication in cyber security, evaluation of authentication processes, and the practical issues of authentication. Several different categories and processes of authentication will be explored along with password cracking techniques, key logging, phishing, and man-in-the-middle attacks. Examples of authentication breaches and ethical hacking techniques will be explored to examine the current technologies and how they can be compromised. Case studies of authentication system implementation and their security breaches are presented. Federated authentication process over different network protocols, topologies, and solutions will be addressed. Related background is developed as needed, allowing students to gain a rich understanding of authentication techniques and the requirements for using them in a secure environment including systems, networks, and the Internet. Students will present
a research project that reflects an understanding of key issues in authentication.

Prerequisites
695.401 Foundations of Information Assurance. 695.421 Public Key Infrastructure and Managing E-Security is recommended.

Instructor: Pak

695.721 Network Security
This course covers concepts and issues pertaining to network security and network security architecture. Topics include mini-cases to develop a network security context. For example, we will assess the NIST (National Institute of Standards and Technology) unified information security framework. This framework is supported by information security standards and guidance, such as a risk management framework (RMF) and continuous monitoring (CM) process. Applied cryptography and information security—encryption algorithms, hash algorithms, message integrity checks, digital signatures, security assessment and authentication, authorization and accounting (AAA), security association, and security key management (generation, distribution, and renewal)—are discussed with consideration given to emerging cryptographic trends, such as the evolution and adoption of NSA’s (National Security Agency’s) Suite B cryptography. This course presents network and network security architecture viewpoints for selected security issues, including various security mechanisms, different layers of wired/wireless security protocols, different types of security attacks and threats and their countermeasures or mitigation, Next Generation Network (NGN) security architecture that supports the merging of wired and wireless communications, and Internet Protocol version 6 implementation and transition. The course concludes with more comprehensive cases that consider cloud computing security architecture issues.

Prerequisites
695.401 Foundations of Information Assurance and 605.471 Principles of Data Communications Networks or 635.411 Principles of Network Engineering.

Instructors: Heinbuch, Podell

Online Option Available

695.722 Covert Channels
It is no secret that the Internet, as well as other channels, is used for covert communications worldwide. It is fairly easy to find the most blatant examples of pgp-encrypted messages from anonymous senders to unidentified recipients. Recent research has described inserting covert data in the unused fields of occasional packets (TCP, IP, UDP, etc.), while sending innocuous routine data in the regular data fields. There are numerous other means of exfiltrating data: disguised as virus updates, masquerading as SPAM, and hiding covert data in massively multiparallel games, to name a few. These means are routinely used by terrorists, narcotraffickers, and others with impunity. This course will cover identification and detection of data hiding, covert communications in IP Networking spaces and in the traditional MLS context, detection, interception, statistical tools for identifying irregularities in ostensibly routine traffic, and other related techniques. Students will be able to identify unauthorized data exfiltration and potential covert channels. Needed background in math and physics will be covered as required.

Prerequisites

Instructor: Staff

695.741 Information Assurance Analysis
This course provides students with an overview of analysis as it applies to information assurance. Analysis is a fundamental part of the information assurance process, and effective analysis informs policy, software development, network operations, and criminal investigations. To enable students to perform effective analysis, the focus of the course is on the analysis process and approach rather than on specific tools. Topics include the collection, use, and presentation of data from a variety of sources (e.g., raw network traffic data, traffic summary records, and log data collected from servers and firewalls). These data are used by a variety of analytical techniques, such as collection approach evaluation, population estimation, hypothesis testing, experiment construction and evaluation, and constructing evidence chains for forensic analysis. Students will construct and critique an analytical architecture, construct security experiments, and retroactively analyze events. The course will also cover selected non-technical ramifications of data collection and analysis, including anonymity, privacy, and legal constraints.

Prerequisites

Instructors: Collins, Janies

Online Option Available

695.742 Digital Forensics Technologies and Techniques
Digital forensics focuses on the acquisition, identification, attribution, and analysis of digital evidence of an event occurring in a computer or network. This course provides a broader scientific understanding of the technologies and techniques used to perform digital forensics. In particular, various signature extraction techniques, detection, classification, and retrieval of forensically interesting patterns will be introduced. This will be complemented by studying fundamental concepts of data processing technologies like compression, watermarking, steganography, cryptography, and multiresolution analysis. Emerging standards along with issues driving the changing nature of this topic will be explored. Anti-forensic techniques that are used to counter forensic analysis will also be covered. Students will be exposed to relevant theory, programming
Cybersecurity

practice, case studies, and contemporary literature on the subject.

Prerequisites
605.412 Operating Systems.

Instructor: Ahmed
Online Option Available

695.744 Reverse Engineering and Vulnerability Analysis

Formerly 695.714 Reverse Engineering and Vulnerability Analysis

This course covers both the art and science of discovering software vulnerabilities. Beginning with the foundational techniques used to analyze both source and binary code, the course will examine current threats and discuss the actions needed to prevent attackers from taking advantage of both known and unknown vulnerabilities. The course will cover passive and active reverse engineering techniques in order to discover and categorize software vulnerabilities, create patches and workarounds to better secure the system, and describe security solutions that provide protection from an adversary attempting to exploit the vulnerabilities. Techniques covered include the use of static analysis, dynamic reverse engineering tools, and fault injection via fuzzing to better understand and improve the security of software.

Instructor: McGuire

695.791 Information Assurance Architectures and Technologies

This course explores concepts and issues pertaining to information assurance architectures (IAA) and technologies, such as cryptographic commercial issues, layered security or defense-in-depth, methods and technologies for critical information infrastructure protection (CIIP), cloud computing security architecture, and IAA and technologies applications. Topics include selected U.S. and international CIIP and Comprehensive National Cybersecurity Initiative (CNCI) Trusted Internet Connections (TIC) multi-agency security information and event management (SIEM) issues. Commercial IAA examples of network security architecture and SIEM are also discussed for evolving enterprise wired and wireless services. The relationships of IAA and technologies with selected multi-tier architectures are discussed for applications such as risk management and enterprise architecture (EA) disciplines, security for virtualized environments; secure software engineering for services, and secure telecommunication for transport. IAA multi-tier architecture issues are illustrated with cases, such as the National Institute of Standards and Technology's (NIST) recommended three-tier approach for organization-wide risk management and a three-tier security controls architecture developed for cybersecurity standards for CIIP that is compatible with guidance from NIST and the International Telecommunication Union-Telecommunication Standardization Sector Study Group 17. Selected applied IAA and technologies are examined in large-scale programs, such as CNCI TIC; the Federal Aviation Administration (FAA) System Wide Information Management (SWIM) Program; and NIST Smart Grid Cyber Security Strategy, Architecture, and High-Level Requirements.

Prerequisites
695.401 Foundations of Information Assurance or equivalent, and 605.471 Principles of Data Communications Networks or 635.411 Principles of Network Engineering.

Instructor: Podell
Online Option Available

695.801 Independent Study in Cybersecurity I

This course permits graduate students in information assurance to work with a faculty mentor to explore a topic in depth or conduct research in selected areas. Requirements for completion include submission of a significant paper or project.

Prerequisites
Seven Cybersecurity graduate courses including the foundation courses, three concentration area courses, and two courses numbered at the 700 level or admission to the Advanced Certificate for Post-Master's Study. Students must also have permission from the instructor.

695.802 Independent Study in Cybersecurity II

Students wishing to take a second independent study in Cybersecurity should sign up for this course.

Prerequisites
695.801 Independent Study in Information Assurance I and permission of a faculty mentor, the student's academic advisor, and the program chair.

550.438 Statistical Methods for Intrusion Detection

This course will give an introduction to the data and methodologies of computer intrusion detection. The focus will be on statistical and machine learning approaches to detection of attacks on computers. Topics will include network monitoring and analysis, including techniques for studying the Internet and estimating the number and severity of attacks; network-based attacks such as probes and denial of service attacks; host-based attacks such as buffer overflows and race conditions; and malicious code such as viruses and worms. Statistical pattern recognition methods will be described for the detection and classification of attacks. Techniques for the visualization of network data will be discussed. The book will be supplemented with readings of various articles.

Prerequisite
550.310 or 550.311, or equivalent.

Instructor: Marchette

550.471 Cryptography and Coding

A first course in the mathematical theory of secure and reliable electronic communication. Topics include finite field arithmetic, error ciphers, one-time pads, the Enigma machine, one way functions, discrete logarithm, primality testing, secret
key exchange, public key cryptosystems, digital signatures, and key escrow.

Prerequisite
550.171 (110.204 with permission of the instructor) linear algebra, computing experience.

Instructor: Fishkind

600.642 Advanced Cryptographic Protocols
This course will focus on advanced cryptographic protocols with an emphasis on open research problems (Applications).

Prerequisite
600.442, 600.443, or permission of the instructor.

Instructor: Ateniese

600.643 Advanced Topics in Computer Security
Topics vary but focus mainly on network perimeter protection, host-level protection, authentication technologies, intellectual property protection, formal analysis techniques, intrusion detection, and similarly advanced topics.

Prerequisite
Any 600-level course in security, including 600.442/443/424 or permission of instructor.

Instructor: Rubin

600.648 Secure Software Engineering
This course examines best practices for designing secure systems, with particular emphasis on software engineering. We review various criteria for designing secure systems and apply those principles to real systems. Students will be exposed to various techniques for analyzing system properties and for verifying program correctness and will be expected to use that knowledge in examining existing protocols. Topics to be covered include the limits of techniques for software protection, such as code obfuscation, tamper-proofing and watermarking, analysis of software-based attacks (and defenses), timing attacks and leakage of information, type safety, and capability systems. A course project is required.

Instructor: Monrose

650.457 Computer Forensics
This course introduces students to the field of computer forensics and will focus on the various contemporary policy issues and applied technologies. Topics to be covered include: legal and regulatory issues, investigation techniques, data analysis approaches, and incident response procedures for Windows and UNIX systems. Homework in this course will relate to laboratory assignments and research exercises. Students should also expect that a group project will be integrated into this course.

Instructor: Lavine

650.459 Software Vulnerability Analysis
This course will examine vulnerabilities in C source, stack overflows, writing shell code, etc. Vulnerabilities in web applications—SQL Injection, cookies, and forceful browsing—as well as vulnerabilities in C binary fuzzing, exploit development without source, and other topics will also be covered.

Instructor: Stubblefield
Information Systems Engineering

With information technology permeating all aspects of modern society, the creation and operation of contemporary information systems is an immensely complex challenge for all organizations. Information systems engineering (ISE) is a multi-disciplinary program that focuses on the analysis, design, development, and integration of systems that enable the effective and efficient use of information in today’s highly dynamic environment. Building on the disciplines of software engineering, systems engineering, cyber security, and networking, ISE employs techniques and methodologies that allow practitioners to create and manage complex information systems to solve real-world problems.

The Master of Science in Information Systems Engineering is designed to appeal to a wide range of individuals. The program balances theory with practice, offers an extensive set of traditional and state-of-the-art courses, and provides the flexibility to accommodate students with various backgrounds. As a result, the program will appeal to engineers and scientists seeking an applied technology program designed to enhance their ability to develop real-world information systems. By providing a broad-based education in the field, the ISE program will allow students to design large-scale information systems, develop efficient network architectures, conduct complex systems analyses, and create sophisticated distributed and secure systems.

Courses are offered across a wide range of topic areas, including software engineering, systems engineering, cyber-security, network engineering, distributed computing, information management, and human–computer interaction. Research and development interests of the faculty span the spectrum of information systems engineering.

Students may take courses at the Applied Physics Laboratory, the Montgomery County Campus, the Dorsey Center, and online. Extensive computing facilities are available and can be reached from any of the sites or from home. A variety of software systems, applications, development tools, and specialized lab facilities are also supported.

Program Committee

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Eleanor Boyle Chlan, Associate Program Chair
Senior Lecturer in Computer Science
Whiting School of Engineering

Michael Smeltzer
Senior Professional Staff
Applied Physics Laboratory

J. Miller Whisnant
Principal Professional Staff
Applied Physics Laboratory

Admission Requirements

Applicants must meet the general requirements for admission to a graduate program as stated in this catalog. In addition, Information Systems Engineering master’s degree candidates must have taken one year of college math including one semester of calculus or discrete mathematics and a course in programming using a modern programming language such as Java or C++. Data Structures may also be required, as determined by an advisor, for students seeking to take selected courses from Computer Science and Cybersecurity.

Applicants who have not taken the prerequisite undergraduate courses may satisfy admission requirements by completing the specified courses with grades of A or B. The program offers the following undergraduate courses, which may be taken as needed to satisfy the prerequisites:

- 605.201 Introduction to Programming Using Java
- 605.202 Data Structures
- 605.203 Discrete Mathematics

Advanced Certificate for Post-Master’s Study in Information Systems Engineering

Applicants who have already completed a master’s degree in a technical discipline are eligible to apply for the Advanced Certificate for Post-Master’s Study in Information Systems Engineering. Six one-term courses must be completed with grades of A or B within three years. At least five of the six courses must be information systems engineering courses and at least two of the information systems engineering courses must be at the 700 level. Students are allowed to take one elective course, subject to advisor approval.

Graduate Certificate in Information Systems Engineering

The Graduate Certificate is directed toward students who may not be currently interested in a master’s degree but are interested in taking specific graduate courses. Five one-term courses must be completed with grades of A or B within three years. At least four of the five courses must be information systems engineering courses. Students are allowed to take one elective course, subject to advisor approval. If the student should decide to pursue the full master’s degree, all courses will apply to the master’s degree provided they meet program requirements, fall within the five-year time limit, and the student declares his or her intention prior to the award of the certificate. Applicants to the Graduate Certificate in Information Systems Engineering must meet the general requirements for admission to a graduate program and must also meet the prerequisites for admission to Information Systems Engineering.
Course Requirements for Master’s Degree
Ten courses, approved by an advisor, must be completed within five years. At least eight courses must be from the ISE curriculum, which includes ISE courses as well as selected courses from Computer Science, Cybersecurity, Systems Engineering, and Technical Management. Three courses must be from the same track and at least two courses must be 700 level. No more than one course with a grade of C, and no course with a grade lower than C, may be counted toward the degree.

Students may take up to two electives from other Whiting School programs. Students who take electives from other programs must meet the specific course and program requirements listed for each course. In the event that the student has transfer courses accepted, they will be considered electives.

Graduate students not pursuing a master’s degree in information systems engineering should consult with their advisor to determine what courses must be successfully completed before 400- or 700-level ISE courses may be taken. 700-level courses are open only to students who have been admitted with graduate status.

Online Options
Students may complete the Master of Science in Information Systems Engineering online, and all students may take advantage of online offerings. While not all courses are available online, a complete program is offered and additional online courses are continually being developed. This increases the flexibility of course offerings for students wishing to pursue studies in either the face-to-face or online format, or a combination of both.

Online course content is identical to that in the face-to-face offerings but available in a paced, asynchronous mode over the Internet. Recorded lectures with associated multi-media content are augmented with online discussions and weekly synchronous office hours. Prospective and current students should consult the EP website for the current online course offerings, course schedules, and procedures for online programs.

Foundation Courses
All students working toward a master’s degree in information systems engineering are required to take the following three foundation courses before taking other graduate courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
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</thead>
<tbody>
<tr>
<td>605.401</td>
<td>Foundations of Software Engineering</td>
</tr>
<tr>
<td>635.401</td>
<td>Foundations of Information Systems Engineering</td>
</tr>
<tr>
<td>695.401</td>
<td>Foundations of Information Assurance</td>
</tr>
</tbody>
</table>

One or more foundation courses can be waived by the student’s advisor if a student has received an A or B in equivalent courses. In this case, the student may replace the waived foundation courses with the same number of other graduate courses and may take these courses after all remaining foundation course requirements have been satisfied.

Graduate Courses by Track
The ISE tracks—including all applicable courses from ISE, Computer Science, Cybersecurity, Systems Engineering, and Technical Management—are as follows:

I. Software Engineering

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>605.401</td>
<td>Foundations of Software Engineering</td>
</tr>
<tr>
<td>605.402</td>
<td>Software Analysis and Design</td>
</tr>
<tr>
<td>605.404</td>
<td>Object Oriented Programming with C++</td>
</tr>
<tr>
<td>605.407</td>
<td>Agile Software Development Methods*</td>
</tr>
<tr>
<td>605.408</td>
<td>Software Project Management*</td>
</tr>
<tr>
<td>605.701</td>
<td>Software Systems Engineering*</td>
</tr>
<tr>
<td>605.702</td>
<td>Service-Oriented Architecture*</td>
</tr>
<tr>
<td>605.704</td>
<td>Object-Oriented Analysis and Design</td>
</tr>
<tr>
<td>605.708</td>
<td>Tools and Techniques of Software Project Management*</td>
</tr>
</tbody>
</table>

II. Systems Engineering

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
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</thead>
<tbody>
<tr>
<td>635.401</td>
<td>Foundations of Information Systems Engineering</td>
</tr>
<tr>
<td>645.462</td>
<td>Introduction to Systems Engineering</td>
</tr>
<tr>
<td>645.467</td>
<td>Management of Systems Projects</td>
</tr>
<tr>
<td>645.742</td>
<td>Management of Complex Systems</td>
</tr>
<tr>
<td>645.753</td>
<td>Enterprise Systems Engineering</td>
</tr>
<tr>
<td>645.757</td>
<td>Foundations of Modeling and Simulation in Systems Engineering</td>
</tr>
<tr>
<td>645.761</td>
<td>Systems Architecting</td>
</tr>
<tr>
<td>645.767</td>
<td>System Conceptual Design</td>
</tr>
<tr>
<td>645.771</td>
<td>System of Systems Engineering</td>
</tr>
<tr>
<td>595.460</td>
<td>Introduction to Project Management</td>
</tr>
<tr>
<td>595.763</td>
<td>Software Engineering Management</td>
</tr>
</tbody>
</table>

III. Cybersecurity

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
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</thead>
<tbody>
<tr>
<td>635.471</td>
<td>Data Recovery and Continuing Operations</td>
</tr>
<tr>
<td>635.476</td>
<td>Information Systems Security</td>
</tr>
<tr>
<td>635.775</td>
<td>Cyber Policy, Law and Cyber Crime Investigation</td>
</tr>
<tr>
<td>695.401</td>
<td>Foundations of Information Assurance</td>
</tr>
<tr>
<td>695.411</td>
<td>Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms*</td>
</tr>
<tr>
<td>695.421</td>
<td>Public Key Infrastructure and Managing E-Security*</td>
</tr>
<tr>
<td>695.422</td>
<td>Web Security*</td>
</tr>
<tr>
<td>695.442</td>
<td>Intrusion Detection*</td>
</tr>
<tr>
<td>695.443</td>
<td>Introduction to Ethical Hacking*</td>
</tr>
<tr>
<td>695.711</td>
<td>Java Security*</td>
</tr>
<tr>
<td>695.712</td>
<td>Authentication Technologies in Cybersecurity*</td>
</tr>
<tr>
<td>695.721</td>
<td>Network Security*</td>
</tr>
<tr>
<td>695.722</td>
<td>Covert Channels</td>
</tr>
<tr>
<td>695.744</td>
<td>Reverse Engineering and Vulnerability Analysis</td>
</tr>
</tbody>
</table>
Information Systems Engineering

IV. Network Engineering

635.411 Principles of Network Engineering
635.711 Advanced Topics in Network Engineering
605.772 Network Management

Additional Network Engineering Choices
For students with appropriate backgrounds, the following courses may be taken toward the network engineering concentration. Advisor approval and permission of the instructor is required.

605.473 High-Speed Networking Technologies*
605.477 Internetworking with TCP/IP I*
605.478 Cellular Communications Systems*
605.771 Wired and Wireless Local and Metropolitan Area Networks*
605.776 Fourth-Generation Wireless Communications: WiMAX and LTE*
605.777 Internetworking with TCP/IP II*
605.778 Voice Over IP*

V. Enterprise and Web Computing

635.482 Website Development
635.483 E-Business: Models, Architecture, Technologies and Infrastructure
605.481 Principles of Enterprise Web Development*
605.484 Agile Development with Ruby on Rails*
605.486 Mobile Application Development for the Android Platform*
605.782 Web Application Development with Java*
605.784 Enterprise Computing with Java*

VI. Information Management

635.421 Principles of Decision Support Systems
605.441 Principles of Database Systems*
605.443 The Semantic Web*
605.444 XML Design Paradigms
605.445 Artificial Intelligence*
605.741 Distributed Database Systems: Cloud Computing and Data Warehouses*
605.744 Information Retrieval*

VII. Human-Computer Interaction

635.461 Principles of Human-Computer Interaction
605.462 Data Visualization

Special Topics

635.792 Management of Innovation
635.795 Information Systems Engineering Capstone Project
635.801 Independent Study in Information Systems Engineering I
635.802 Independent Study in Information Systems Engineering II

*This course requires 605.202 Data Structures of equivalent as a prerequisite.

Course Descriptions

635.401 Foundations of Information Systems Engineering
Creating and operating large-scale information systems requires a holistic approach that manages the blending of software, hardware, networks, and security inherent in modern systems. This course introduces key elements and processes required for designing, analyzing, developing, and integrating complex information systems. The course focuses on the systems engineering approach with specific emphasis on design, development, and deployment. Topics covered include requirements engineering, architecture development, security engineering, cost-benefit analysis, information and networking technologies, and operations.

Instructors: Chavis, Pascale
Online Option Available

635.411 Principles of Network Engineering
This course provides an overview of networking and telecommunications. Topics include analog and digital voice; data, imaging, and video communications fundamentals, including signaling and data transmissions; and basic terminology. The course also covers networking and telecommunication techniques, applications technology, and networking topologies and internetworking architectures. Specific areas discussed include LAN system fundamentals, such as Ethernet and token ring; and WAN system fundamentals, such as circuit-switching, packet-switching, X.25, frame relay, and Asynchronous Transfer Mode. The open systems interconnection (OSI) reference model standard is also described and compared with other network layering standards used in telecommunications.

Instructors: Burbank, Romano
Online Option Available

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635.421 Principles of Decision Support Systems
This course focuses on the use and application of information systems to support the decision-making process. Knowledge-based systems, neural networks, expert systems, electronic meeting systems, group systems, and web-based systems are discussed as a basis for designing and developing highly effective decision support systems. Data models, interactive processes, knowledge-based approaches, and integration with database systems are also described. Theoretical concepts are applied to real-world applications.

Instructor: T. Felikson
Online Option Available

635.461 Principles of Human–Computer Interaction
Well-designed human–computer interaction is critical to the success of computer and information systems. This course focuses on the HCI design process and covers the underlying scientific principles, HCI design methodology, and the user-interface technology used to implement HCI. Topics include human cognition, HCI theories, user observation and task analysis, prototyping and evaluation techniques, user interface modalities and graphical user interface components, and accessibility. Selected additional topics may include HCI in website design, support of collaborative work, human interaction with automation, and ubiquitous computing. Student design projects are an integral part of the course. Reading the current HCI research literature is also required.

Instructor: Montemayer
Online Option Available

635.471 Data Recovery and Continuing Operations
Data recovery and continuing operations refers to the processes, plans, and technologies required for an enterprise to achieve resiliency given unexpected events that may disrupt IT operations. This course provides an overview of the storage technologies to address backup, disaster recovery, and business continuity. Technologies that address auditing, redundancy, and resiliency in the infrastructure (e.g., networks, power, cooling, etc.) are described. Beyond the technologies, processes and plans for continuing operations are covered to include issues such as business continuity, disaster recovery, and risk management.

Prerequisite
635.421 Principles of Decision Support Systems is recommended and may be taken concurrently.

Instructor: Cost

635.476 Information Systems Security
This course describes the systems security engineering process with a focus on security during the design and implementation of information systems. Topics include design principles, risk assessment, and security metrics. The course will present the processes that have been defined and published by the federal government for designing and evaluating secure information systems.

Instructor: Reich
Online Option Available

635.482 Website Development
This course covers the design and implementation of websites. Various web standards, as developed by the World Wide Web Consortium and by browser manufacturers, are studied. HTML 4.01 and XHTML 1.0 specifications are covered, including topics such as text control, images, hypertext links, tables, frames, and embedded objects (e.g., video and applets). Cascading Style Sheets (CSS1 and CSS2), a web scripting language (such as Javascript), CGI programming, and their use in Dynamic HTML are also covered. Design and development topics include ease of navigation, download time, maintaining a consistent look and feel across multiple pages, making a website work well across multiple browsers, and web server selection and configuration.

Instructor: Noble
Online Option Available

635.483 E-Business: Models, Architecture, Technologies and Infrastructure
This course explores fundamental aspects of the e-Business phenomenon that is currently sweeping through the global economy, as well as design principles and technology used to build computer-based systems in order to support the notion of e-Business. E-Business (electronic business) is an umbrella term, an interdisciplinary topic encompassing both business and technology. This topic addresses a variety of business activities, business processes, and strategic business functions conducted over the Internet in order to service customers, to collaborate with business partners, and to maintain and sustain competitive advantage in the networking economy. The course introduces contemporary management philosophies as they have come to be used for the marketing, selling, and distribution of goods and services through the Internet and other electronic media. The course explores approaches of defining drivers and use cases of conducting electronic business. This course provides an overview of principles and analysis of different models of electronic business. It enables students to design effective e-Business models built on a foundation of business concepts, knowledge of the e-Business environment, and an understanding of the influence of the Internet on business stakeholders, including customers, suppliers, manufacturers, service makers, regulators, managers, and employees. In this course students undertake value analysis and learn to describe value propositions. Business architecture and software infrastructure used to engineer and build e-Business systems will be explained. The modern information technologies associated with the delivery of business capabilities over the Internet will be discussed. The course content will be reinforced by a variety of assignments.

Instructors: Chittargi, T. Felikson
635.711 Advanced Topics in Network Engineering

This course is designed to provide an advanced treatment of key topic areas in networking and telecommunications for students who have mastered the basic principles of network engineering. Key operational systems, protocols, and technologies are explored in local, wide, metro-area, storage, and wireless networking. Major topic areas include advanced LAN/WLAN technologies (Power over Ethernet, IEEE 802.1x authentication, VLANS, link aggregation, etc.), Storage Area Network technologies, Virtualized/Cloud networking, Optical Networking, IPv6, Spanning Tree and Dynamic IP routing protocols, “Last-Mile” Networking (DSL, Cable Moderns, etc.), Label Switching, Multicasting, and Multicast routing, real-time application support mechanisms, Quality of Service protocols, Advanced Transport Layer topics (Congestion Notification, TCP options, etc.), and Network Security (address translation, VPNs, stateful inspection, etc.). A major component of the course will be a design project on one of the topic areas covered in the class.

Prerequisite
635.411 Principles of Network Engineering or 605.471 Principles of Data Communications Networks or equivalent.

Instructor: Romano

635.775 Cyber Policy, Law and Cyber Crime Investigation

Technical solutions for investigating cyber attacks and restoring our information systems must be balanced against, and work within, laws, regulations, and policies that govern information technology. The objective of this course is to provide a comprehensive overview of the legal and policy structures that must be considered in building effective compliance, investigation, and enforcement capabilities. Students will explore offensive and defensive aspects of evidence collection, forensic investigation, privacy, reporting, and implementing corrective actions. Students will develop and submit a management plan for improving compliance, investigation, and enforcement capabilities within an organization’s systems. Upon completing this course, students will be able to provide improved leadership within the teams that manage compliance, investigation, and enforcement, increase their ability to collaborate with legal and business stakeholders, and improve their ability to develop policies that align to legal requirements.

Instructors: Resch and Ritter

635.792 Management of Innovation

A critical issue for entrepreneurs and technical managers is how to translate opportunity into competitive advantage. This course explores the management of innovation, including the technical transition of applied R&D into products, the planning and launching of new products, and product management. Management of discontinuous technologies will be explored. The impact of competition by the introduction of new discontinuous technology will be addressed. Managing engineers through the creative process, as well as innovation and technological evolution, will be covered. The course includes both formal and guest lectures. Case studies will be used as an important learning vehicle.

Instructor: Husick

635.795 Information Systems Engineering Capstone Project

This course is designed for students who would like to conduct a major independent project involving a substantial enterprise information system design that builds upon elements of the ISE curriculum. The project includes requirements analysis, IT architecture design, network design, software integration, decision support applications, and deployment planning. Interim deliverables include presentations to the course advisors. Project proposals are required and a mentor will be assigned to the student.

Prerequisites
Completion of eight courses in the ISE curriculum, including all ISE foundation courses.

Course Notes
Students may not receive graduate credit for both 635.795 and 635.802 Independent Study in Information Systems Engineering II.

Instructor: Staff

635.801 Independent Study in Information Systems Engineering I

This course permits graduate students in Information Systems Engineering to work with a faculty mentor to explore a topic in depth or conduct research in selected areas. Requirements for completion include submission of a significant paper.

Prerequisites
Seven ISE graduate courses including the foundation courses, three concentration area courses, and two courses numbered 635.7xx; or admission to the advanced certificate for post-master’s study. Students must also have permission of a faculty mentor, the student’s academic advisor, and the program chair.

635.802 Independent Study in Information Systems Engineering II

Students wishing to take a second independent study in information systems engineering should sign up for this course.

Prerequisites
635.801 Independent Study in Information Systems Engineering I and permission of a faculty mentor, the student’s academic advisor, and the program chair.

Course Notes
Students may not receive graduate credit for both 635.802 and 635.795 Information Systems Engineering Capstone Project.
Materials Science and Engineering

Materials science and engineering is concerned with the structure, processing, properties, and applications of materials. Materials scientists investigate how the structure and composition of materials affect their properties and performance. Materials engineers develop, modify, and apply materials to specific technological applications.

The JHU Department of Materials Science and Engineering offers three different graduate degrees; the PhD, the MSE (Master of Science in Engineering), and the MMSE (Master of Materials Science and Engineering). The MMSE is offered through the Engineering for Professionals program and is described in detail below. Information about the PhD and MSE can be obtained from the Arts and Sciences/Engineering undergraduate and graduate programs catalog.

The MMSE degree is designed specifically as a part-time degree that can be completed by taking courses in the late afternoon or evening. It is viewed as a terminal degree and is generally not considered sufficient preparation to continue toward the PhD. Those interested in pursuing a PhD degree should consider applying to the department for the MSE degree. Please note that the application materials for the PhD and MSE degrees are different from the EP application used in applying for the MMSE degree.

The Department of Materials Science and Engineering has active research programs in biomaterials, nanomaterials and nanotechnology, electrochemistry, thin films, mechanics of materials, electronic materials, and physical metallurgy.

Program Committee

Robert C. Cammarata, Program Chair
Professor, Materials Science and Engineering
Whiting School of Engineering

James B. Spicer
Professor, Materials Science and Engineering
Whiting School of Engineering

Jennifer Sample
Senior Professional Staff
Applied Physics Laboratory

Admission Requirements

The Master of Materials Science and Engineering (MMSE) program is best suited to students who have received undergraduate degrees in engineering or science. Applicants are expected to have completed a mathematics sequence through differential equations and courses in general physics and chemistry. Applicants must meet the general requirements for graduate study outlined in this catalog. The program committee is willing to consider applicants who do not meet the general admission requirements in exceptional cases.

Individuals who desire a non-degree status for taking courses may request consideration for Special Student status. Regardless of level, courses taken while a Special Student do not necessarily count toward fulfillment of degree requirements if the student is subsequently accepted as a degree candidate. This status is normally extended for one year with reapplication required for continuation.

Course Requirements

The Master of Materials Science and Engineering degree is awarded after successful completion of 10 one-term courses within five years. All students are required to take 515.401 Structure and Properties of Materials and 515.402 Thermodynamics and Kinetics. Of the remaining eight electives, at least one must be 600 level or higher. Courses offered by the Department of Materials Science and Engineering are acceptable as electives. Students interested in taking the 515.730/731 Materials Science and Engineering Project must get prior approval from the departmental coordinator and be assigned an advisor.

Below is a list of acceptable course electives offered by other departments. Students wishing to take a course not on the list to satisfy the degree requirements must get prior approval from the departmental coordinator. The program of 10 courses that the student plans to pursue must be approved by the departmental coordinator. Students may also select electives from the courses listed below under the Nanotechnology Concentration.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>525.406</td>
<td>Electronic Materials</td>
</tr>
<tr>
<td>525.407</td>
<td>Introduction to Electronic Packaging</td>
</tr>
<tr>
<td>535.406</td>
<td>Advanced Strength of Materials</td>
</tr>
<tr>
<td>535.720</td>
<td>Analysis and Design of Composite Structures</td>
</tr>
<tr>
<td>545.426</td>
<td>Introduction to Biomacromolecules</td>
</tr>
<tr>
<td>545.440</td>
<td>Micro- and Nanotechnology</td>
</tr>
<tr>
<td>565.729</td>
<td>Structural Mechanics</td>
</tr>
<tr>
<td>585.409</td>
<td>Mathematical Methods for Applied Biomedical Engineering</td>
</tr>
<tr>
<td>585.608</td>
<td>Biomaterials</td>
</tr>
<tr>
<td>585.609</td>
<td>Cell Mechanics</td>
</tr>
<tr>
<td>585.618</td>
<td>Biological Fluid and Solid Mechanics</td>
</tr>
<tr>
<td>615.441</td>
<td>Mathematical Methods for Physics and Engineering</td>
</tr>
<tr>
<td>615.451</td>
<td>Statistical Mechanics and Thermodynamics</td>
</tr>
<tr>
<td>615.746</td>
<td>Nanoelectronics: Physics and Devices</td>
</tr>
<tr>
<td>615.757</td>
<td>Solid-State Physics</td>
</tr>
<tr>
<td>615.760</td>
<td>Physics of Semiconductor Devices</td>
</tr>
</tbody>
</table>

Nanotechnology Concentration

Nanotechnology Course Requirements

Students enrolled in the Master of Science in Materials Science and Engineering program can elect to pursue the Nanotechnology Concentration. Two focus areas are offered: the Nanomaterials focus area and the Biotechnology focus area.
For either focus area, the student must successfully complete the core courses and then at least three courses selected from the corresponding focus area course list. The student, in consultation with the departmental coordinator, will select the other courses (for a total of 10) from the part-time or full-time graduate courses offered by the Whiting School of Engineering. The set of 10 courses must represent a coherent educational program and be approved by the departmental coordinator. At least one of the non-core courses must be 600 level or higher.

Nanotechnology Concentration—Required Core Courses
All students are required to take 515.401 Structure and Properties of Materials, 515.402 Thermodynamics and Kinetics of Materials, 515.416 Introduction to Nanotechnology, and 515.417 Nanomaterials. The program of 10 courses that the student plans to pursue must be approved by the departmental coordinator.

A list of acceptable electives for the Nanomaterials and Biotechnology focus areas are given below. Students who wish to take courses not listed below need to get prior approval from the departmental coordinator.

I. Nanomaterials Focus Area

Materials Science and Engineering Courses
510.611/612 Solid-State Physics
515.730/731 Materials Science and Engineering Project

Applied Biomedical Engineering Courses
580.442 Tissue Engineering
580.641 Cellular Engineering
585.209 Organic Chemistry
585.405/406 Physiology for Applied Biomedical Engineering
585.409 Mathematical Methods for Applied Biomedical Engineering
585.608 Biomaterials
585.609 Cell Mechanics
585.610 Biochemical Sensors
585.614 Applications of Physics and Technology to Biomedicine
585.618 Biological Fluid and Solid Mechanics
585.626 Biomimetics in Biomedical Engineering

Applied Physics Courses
615.441 Mathematical Methods for Physics and Engineering
615.746 Nanoelectronics: Physics and Devices
615.747 Sensors and Sensor Systems
615.757 Solid-State Physics

Chemical and Biomolecular Engineering Courses
540.439 Polymer Nanocomposites
545.612 Interfacial Phenomena in Nanostructure Materials

Electrical and Computer Engineering Courses
525.406 Electronic Materials
525.421 Introduction to Electronics and the Solid State I

Mechanical Engineering Courses
530.487 Introduction to Microelectromechanical Systems (MEMS)
530.652 Bridging Length Scales in Materials Behavior

II. Biotechnology Focus Area

Materials Science and Engineering Courses
510.606 Chemical and Biological Properties of Materials
510.617 Advanced Topics in Biomaterials
515.730/731 Materials Science and Engineering Project

Applied Biomedical Engineering Courses
580.442 Tissue Engineering
580.641 Cellular Engineering
585.405/406 Physiology for Applied Biomedical Engineering
585.409 Mathematical Methods for Applied Biomedical Engineering
585.608 Biomaterials
585.609 Cell Mechanics
585.610 Biochemical Sensors
585.614 Applications of Physics and Technology to Biomedicine
585.618 Biological Fluid and Solid Mechanics
585.626 Biomimetics in Biomedical Engineering

Chemical and Biomolecular Engineering Course
545.612 Interfacial Phenomena in Nanostructure Materials

Course Descriptions

510.407 Biomaterials II
This course focuses on the interaction of biomaterials with the biological system and applications of biomaterials. Topics include host reactions to biomaterials and their evaluation, cell–biomaterials interaction, biomaterials for tissue engineering applications, biomaterials for controlled drug and gene delivery, biomaterials for cardiovascular applications, biomaterials for orthopedic applications, and biomaterials for artificial organs.

Course Notes
Also listed as 510.607.

Instructor: Mao
510.422  **Micro- and Nano-Structured Materials and Devices**
Almost every materials property changes with scale. We will examine ways to make micro- and nano-structured materials and discuss their mechanical, electrical, and chemical properties. Topics include the physics and chemistry of physical vapor deposition, thin film patterning, and microstructural characterization. Particular attention will be paid to current technologies including computer chips and memory, thin film sensors, diffusion barriers, protective coatings, and microelectromechanical devices (MEMS).

**Course Notes**
Also listed as 510.622.

510.426  **Biomolecular Materials**
Topics covered by this course include structure and function of cellular molecules (lipids, nucleic acids, proteins, and carbohydrates); structure and function of molecular machines (enzymes for biosynthesis, motors, pumps); protein synthesis using recombinant nucleic acid methods; advanced materials development; interactions of biopolymers, lipid membranes, and their complexes; mean field theories, fluctuation, and correlation effects; self-assembly in biomolecular materials; biomedical applications; and characterization techniques.

**Course Notes**
Same as 510.626.

Instructor: **Hristova**

510.604  **Mechanical Properties of Materials**
This course introduces the properties and mechanisms that control the mechanical performance of materials. Topics include mechanical testing, tensor description of stress and strain, isotropic and anisotropic elasticity, plastic behavior of crystals, dislocation theory, mechanisms of microscopic plasticity, creep, fracture, and deformation of fracture of polymers.

**Prerequisites**
510.601 or permission of instructor.

**Instructor:** **Staff**

510.605  **Electronic, Optical, and Magnetic Properties of Materials**
This course is an overview of electrical, optical, and magnetic properties arising from the fundamental electronic and atomic structure of materials. Continuum materials properties are developed through examination of microscopic processes. Topics to be covered include quantum mechanical structure of solids including electronic band structure; electrical, thermal, and ionic conduction; response of materials to electromagnetic fields including dielectric permittivity, ferroelectric materials, and piezoelectricity; magnetic behavior including paramagnetism and ferromagnetism, magnetic permeability, magnetic domains, and magnetostriction; interactions of electromagnetic radiation with materials (absorption, reflection, refraction, and scattering, electro- and magneto-optic effects); and superconductivity. Emphasis will be placed on both fundamental principles and applications in contemporary materials technologies.

**Prerequisites**
510.601.

**Instructor:** **Staff**

510.606  **Chemical and Biological Properties of Materials**
This course introduces the chemical and biological properties of organic and inorganic materials. Topics include an introduction to polymer science, polymer synthesis, chemical synthesis and modification of inorganic materials, biomineralization, biosynthesis and properties of natural materials (proteins, DNA, and polysaccharides), structure–property relationships in polymeric materials (synthetic polymers and structural proteins), and materials for biomedical applications.

**Prerequisites**
Undergraduate chemistry and biology, or permission of instructor.

**Instructor:** **Staff**

510.607  **Biomaterials II**
This course focuses on the interaction of biomaterials with the biological system and applications of biomaterials. Topics include host reactions to biomaterials and their evaluation, cell–biomaterials interaction, biomaterials for tissue engineering applications, biomaterials for controlled drug and gene delivery, biomaterials for cardiovascular applications, biomaterials for orthopedic applications, and biomaterials for artificial organs.

**Course Notes**
Also listed as 510.407.

**Instructor:** **Mao**

510.608  **Electrochemistry**
Topics covered by this course include thermodynamics of electrochemical interfaces, including electrochemical potential, the Nernst equation, ion–solvent interactions, and double layer theory; charge transfer kinetics for activation and diffusion controlled processes; and analysis of kinetics at various electrodes, including redox reactions, metal-ion electrodes, and semiconductor electrodes. Electroanalytical techniques are also discussed, including those related to bioelectrochemistry and semiconductor electrochemistry. Selected reactions of technological importance are evaluated, including the hydrogen evolution reaction, oxygen reduction, electrodeposition, and energy generation and storage.

**Prerequisites**
Undergraduate prerequisite: Introductory chemistry or permission of instructor.

**Instructor:** **Searson**
510.611/612  **Solid-State Physics**  
This course provides an introduction to solid-state physics for advanced undergraduates and graduate students in physical science and engineering. Topics include crystal structure of solids; band theory; thermal, optical, and electronic properties; transport and magnetic properties of metals, semiconductors, and insulators; and superconductivity. The concepts and applications of solid-state principles in modern electronic, optical, and structural materials are also discussed.  
**Instructors:** Poehler, Staff  

510.617  **Advanced Topics in Biomaterials**  
This course reviews recent advances in biomaterials focusing on the design principles in polymeric materials and scaffolds. It will cover topics from molecular designs of polymeric biomaterials, materials surface engineering, and processing of polymeric scaffolds, to manipulation of cellular behaviors through materials engineering. Specific examples in cell and tissue engineering, and drug and gene delivery, will be discussed.  
**Instructor:** Staff  

510.618  **Electronic and Photonic Processes and Devices**  
This course is intended for advanced undergraduates and graduate students and will cover the fundamentals and properties of electronic and optical materials and devices. Subject matter will include a detailed and comprehensive discussion of the physical processes underlying modern electronic and optical devices. Detailed descriptions of modern semiconductor devices such as lasers and detectors used in optical communications and information storage and processing will be presented. Cross-listed with Electrical and Computer Engineering.  
**Instructor:** Staff, Poehler  

510.626  **Biomolecular Materials I**  
Topics covered by this course include structure and function of cellular molecules (lipids, nucleic acids, proteins, and carbohydrates); structure and function of molecular machines (enzymes for biosynthesis, motors, pumps); protein synthesis using recombinant nucleic acid methods; advanced materials development; interactions of biopolymers, lipid membranes, and their complexes; mean field theories, fluctuation and correlation effects; self-assembly in biomolecular materials; biomedical applications; and characterization techniques.  
**Course Notes**  
Also listed as 510.426.  
**Instructor:** Hristova  

510.636  **Electronic Materials Science**  
This course provides an introduction to semiconductor device physics, including band structure, current flow, capacitance, and recombination. Also covered are barriers and junctions, transistors, crystallography and crystalline defects; processing (ion implantation, thermal oxidation, metallization, reaction kinetics, and diffusion barriers); heterostructures and heteroepitaxy; and assembly and packaging.  
**Instructor:** Searon  

510.650  **Principles of Quantum Physical Interactions**  
Topics covered by this course include foundational quantum-mechanical study of nanometer-scale electronic and optoelectronic materials structures, principles of quantum physics, stationary-state eigenfunctions and eigenvalues for one-dimensional potentials, interaction with the electromagnetic field, electronic conduction in solids, surface and interface effects, tunneling microscopy, and spectroscopy.  
**Prerequisites**  
110.201 and 110.302 or equivalent, 510.311.  
**Instructor:** Spicer  

510.657  **Materials Science of Thin Films**  
The processing, structure, and properties of thin films are discussed emphasizing current areas of scientific and technological interest. Topics include elements of vacuum science and technology; chemical and physical vapor deposition processes; film growth and microstructure; chemical and microstructural characterization methods; epitaxy; mechanical properties such as internal stresses, adhesion, and strength; and technological applications such as superlattices, diffusion barriers, and protective coatings.  
**Instructor:** Weihs  

510.661  **Alloy Stability and Phase Diagrams**  
This course examines the fundamentals of alloy theory and phase diagram modeling to understand the formation, stability, and evolution of alloy phases and microstructures. Topics to be covered include structures of intermediate alloy phases such as electron phases, Laves phases, interstitial phases, valency compounds, and superlattices; stability criteria of solid solutions and intermediate alloy phases, including Hume-Rothery rules, theories of ordering, electronic theories of solid solubility and alloy stability, and elastic instability; thermodynamic and kinetic analysis of phase and microstructural instability due to different driving forces: chemical, strain, interfacial, gradient, etc.; balance of kinetic stability and thermodynamic instability: formation of highly metastable or unstable phases far from equilibrium; and calculations of the phase stability ranges in terms of equilibrium or metastable binary or multi-component phase diagrams using CALPHAD modeling.  
**Instructor:** Ma  

510.665  **Advanced Topics in Thermodynamics of Materials**  
Selected areas of thermodynamics will be examined in depth with the aim of understanding the ideas and assumptions underlying results of importance to materials science. Attempts will be made to be as rigorous as possible without
Materials Science and Engineering

515.445 Systems Engineering for Microscale and Nanoscale Technologies
This course will concentrate on the use of systems engineering at the micro and nano levels. One major roadblock to this process is a generally limited understanding of exactly how to apply systems engineering principles and management processes to the integration of newer, small-scale technologies. Focusing on this problem of consolidating disciplines, contributing lecturers will illustrate the interdependence between nanotechnology and systems engineering, making it easier for those interested in these two distinct fields to understand and optimize their application of the other. To help students from these different domains successfully combine heterogeneous, mixed-scale elements, contributors assess the evolution of micro- and nanoscale technology development and its impact on everything from laboratory concepts to actualized products in health, automotive, aerospace, communication, and many other fields. The course outlines new approaches to developing smart systems. It also clarifies the capabilities of micro- and nanotechnologies, including how they interface with each other and with macro systems.

Instructor: Sample

515.730/731 Materials Science and Engineering Project
This course is an individually tailored, supervised project that offers research experience through work on a special problem related to each student’s field of interest. Upon completion of this course, a written essay must be submitted. Final approval of the essay will be given by the faculty advisor.

Prerequisites
All other coursework should be completed before this project begins (or at least completed concurrently with this project). Consent of advisor is required.

Course Notes
This course is available only to students in the Master of Materials Science and Engineering program.

Instructor: Staff

525.406 Electronic Materials
Materials and the interfaces between them are the key elements in determining the functioning of electronic devices and systems. This course develops the fundamental parameters of the basic solid material types and their relationships to electrical, thermal, mechanical, and optical properties. The application of these materials to the design and fabrication of electronic components, including integrated circuits, passive components, and electronic boards, modules, and systems, is described.

Prerequisites
An undergraduate degree in engineering, physics, or materials science; familiarity with materials structures and electronic devices.

Instructor: Charles
525.407  Introduction to Electronic Packaging
Topics include fundamentals of electronic packaging engineering and basic concepts in thermal, mechanical, electrical, and environmental management of modern electronic systems. Emphasis is on high-frequency (and high-speed) package performance and its achievement through the use of advanced analytical tools, proper materials selection, and efficient computer-aided design. Packaging topics include die and lead attachment, substrates, hybrids, surface-mount technology, chip and board environmental protection, connectors, harnesses, and printed and embedded wiring boards.

Prerequisites
An undergraduate degree in a scientific or engineering area, including familiarity with computer-aided design and engineering analysis methods for electronic circuits and systems.

Instructor: Charles

525.421  Introduction to Electronics and the Solid State I
Fundamentals of solid state and device physics are presented. Topics in solid-state physics include crystal structure, lattice vibrations, dielectric and magnetic properties, band theory, and transport phenomena. Concepts in quantum and statistical mechanics are also included. Basic semiconductor device operation is described with emphasis on the p-n junction.

Prerequisites
An undergraduate degree in electrical engineering or the equivalent.

Instructor: Charles

530.652  Bridging Length Scales in Materials Behavior
This course addresses the tools needed to bridge the macroscopic, continuum, mesoscopic, microscopic, and atomic length scales that currently bound the physical theories and models that have been developed to describe materials behavior.

Instructor: Henker

535.406  Advanced Strength of Materials
This course reviews stress and strain in three dimensions, elastic and inelastic material behavior, and energy methods. It also covers use of the strength of materials approach to solving advanced problems of torsion, bending of beams and plates, buckling of columns, stress concentrations, and fracture mechanics. The use of finite element analysis in solving problems in mechanics will be introduced as well.

Prerequisites
Required course for Solid Mechanics track.

Instructor: Burkhardt

When Offered: Fall

535.720  Analysis and Design of Composite Structures
Topics in this course include anisotropic elasticity, laminate analysis, strength of laminates, failure theories, bending, buckling, and vibration of composite plates. The second part of the course is devoted to the applications of the structural analysis of composite structures by means of finite-elements computer codes.

Instructor: Staff

545.426  Introduction to Biomacromolecules
This course introduces modern concepts of polymer physics to describe the conformation and dynamics of biological macromolecules such as filamentous proteins and nucleic acids. We will introduce scattering techniques and micromanipulation techniques, as well as rheology, as applied to the study of polymers.

Instructor: Wirtz

545.440  Micro- and Nanotechnology
Micro-/nanotechnology is the field of fabrication, characterization, and manipulation of extremely small objects (dimensions on the micron- to nanometer-length scale). Microscale objects, because of their small size, are expected to be at the frontier of technological innovation for the next decade. This course will include a description of the materials used in microtechnology, methods employed to fabricate nanoscale objects, techniques involved in characterizing and exploiting the properties of small structures, and examples of how this technology is revolutionizing the areas of electronics and medicine.

Course Notes
This course is cross-listed with 540.640.

Instructor: Gracias

545.612  Interfacial Phenomena in Nanostructure Materials
All properties of materials change when encountered or fabricated with nanoscale structure. In this class, we will examine how the properties of nanostructured materials differ from their macroscopic behavior, primarily due to the presence of large interfacial areas relative to the volume scale. General topics include the structure of nanostructured materials (characterization and microscopy), thermodynamics (effects of high curvatures and surface elasticity), kinetics and phase transformations (diffusion and morphological stability), and electronic properties (quantum confinement and effects of dimensionality).

Course Notes
This is a course of the Whiting School’s Department of Chemical and Biomolecular Engineering.

Instructor: Staff
565.729 Structural Mechanics
This course presents basic solid mechanics for structural engineers, including stress, strain, and constitutive laws; linear elasticity and visco-elasticity; introduction to nonlinear mechanics; static, dynamic, and thermal stresses; specialization of theory to one- and two-dimensional cases; plane stress and plane strain, rods, and beams; work and energy principles; and variational formulations.

Course Notes
This course is a requirement for the Structural Engineering concentration.

Instructor: Staff

580.442 Tissue Engineering
This course focuses on the application of engineering fundamentals to designing biological tissue substitutes. Concepts of tissue development, structure, and function will be introduced. Students will learn to recognize the majority of histological tissue structures in the body and understand the basic building blocks of the tissue and clinical need for replacement. The engineering components required to develop tissue-engineered grafts will be explored including biomechanics and transport phenomena along with the use of biomaterials and bioreactors to regulate the cellular microenvironment. Emphasis will be placed on different sources of stem cells and their applications to tissue engineering. Clinical and regulatory perspectives will be discussed. Co-listed with 580.642.

Prerequisites

Instructors: Elisseeff, Grayson

580.641 Cellular Engineering
This course focuses on principles and applications in cell engineering. Class lectures include an overview of molecular biology fundamentals, protein/ligand binding, receptor/ligand trafficking, cell-cell interactions, cell-matrix interactions, and cell adhesion and migration at both theoretical and experimental levels. Lectures will cover the effects of physical (e.g., shear stress, strain), chemical (e.g., cytokines, growth factors), and electrical stimuli on cell function, emphasizing topics on gene regulation and signal transduction processes. Furthermore, topics in metabolic engineering, enzyme evolution, polymeric biomaterials, and drug and gene delivery will be discussed. This course is intended as Part 1 of a two-semester sequence recommended for students in the Cell and Tissue Engineering focus area. Meets with 580.441.

Prerequisites
580.221 or 020.305 and 020.306 (or equivalent) and 030.205

Instructors: Green, Yarema

585.405/406 Physiology for Applied Biomedical Engineering
This two-semester sequence is designed to provide the physiological background necessary for advanced work in biomedical engineering. A quantitative model-oriented approach to physiological systems is stressed. First-term topics include the cell and its chemistry, transport and the cell membrane, properties of excitable tissue and muscle, the cardiovascular system, and the respiratory system. The second-term course covers anatomy of the nervous system, structure and functions of the auditory and visual systems, motor systems, the kidney and gastrointestinal tract, and the neural and neuroendocrine control of the circulation.

Instructors: Berman, Haase, Staff

585.409 Mathematical Methods for Applied Biomedical Engineering
The course covers mathematical techniques needed to solve advanced problems encountered in applied biomedical engineering. Fundamental concepts are presented with emphasis placed on applications of these techniques to biomedical engineering problems. Topics include solution of ordinary differential equations using the Laplace transformation, Fourier series and integrals, solution of partial differential equations including the use of Bessel functions and Legendre polynomials, and an introduction to complex analysis.

Prerequisites
Familiarity with multi-variable calculus, linear algebra, and ordinary differential equations.

Instructor: Rio

585.608 Biomaterials
This course covers the fundamentals of the synthesis, properties, and biocompatibility of metallic, ceramic, polymeric, and biological materials that come in contact with tissue and biological fluids. Emphasis is placed on using biomaterials for both hard and soft tissue replacement, organ replacement, coatings and adhesives, dental implants, and drug delivery systems. New trends in biomaterials, such as electrically conductive polymers, piezoelectric biomaterials, and sol-gel processing, are discussed, and the recent merging of cell biology and biochemistry with materials is examined. Case studies and in-class scenarios are frequently used to highlight the current opportunities and challenges of using biomaterials in medicine.

Prerequisites
585.209 Organic Chemistry.

Instructor: Potember

585.609 Cell Mechanics
The class starts with introductory lectures on the place of cell mechanics in the broader areas of cell biology, physiology, and biophysics, where the general topics of cell structure, motility, force generation, and interaction with the extracellular matrix are considered. Three important case studies are discussed: blood cells, vascular endothelial cells, and cochlear hair cells. The analysis of each of these cases includes constitutive relations, experiments to estimate cellular parameters, and biological and physiological implications. The constitutive
relations are based on nonlinear viscoelasticity in the cases of blood and endothelial cells and linear piezoelectricity in the case of hair cells. The necessary components of engineering mechanics of solids and fluids are introduced. The effective mechanical characteristics of the cell are related to the structure and properties of the cellular membrane, cytoskeleton, and nucleus. Micropipette aspiration, atomic force microscopy, and magnetic cytometry techniques are discussed in detail. Students also read and make presentations of original journal papers covering additional topics, which exposes them to the professional literature and hones their communication skills.

Instructor: Spector

585.610 Biochemical Sensors
This course covers the fundamental principles and practical aspects of chemical sensing of physiological signals. The focus of the course is on the electrochemistry and biophysical chemistry of biological sensing elements and their integration with signal transducers. Other topics covered include design and construction of practical sensors, processing and interpretation of signal outputs, and emerging technologies for biosensing.

Instructors: McCully, Staff

585.614 Applications of Physics and Technology to Biomedicine
The goal of this course is to expose students to several concrete examples of how physical and technological methods are used in biomedicine. Examples will be chosen from ophthalmology (e.g., how the optical properties of the eye's cornea are related to its ultrastructure, applications of lasers, methods of measuring ocular blood flow and intraocular pressure); biomedical optics (e.g., microscopy, optical coherence tomography); neural signal processing; medical image processing; and MRI. Topics will be presented by instructors who are actively engaged in research in the various areas.

Instructors: McCally, Staff

585.618 Biological Fluid and Solid Mechanics
The goal of this class is to learn the relation between the mechanics and physiology (biology) of tissues and cells. This relation is demonstrated by introducing general models of solid and fluid mechanics and applying them to the cardiovascular system and bones. In particular, the arterial wall and endothelial cell mechanics as well as bone anisotropic properties and remodeling are discussed. The course also shows how theoretical models are used to interpret experiments and how experimental data are used to estimate important parameters (constants) of the models. Experiments with biaxial stretching, micropipette aspiration, and atomic force microscopy commonly used to probe the mechanical properties of tissues and cells are discussed in detail. The models include anisotropic linear elasticity, nonlinear elasticity, viscoelasticity, and Newtonian (non-Newtonian) fluid dynamics.

Instructor: Spector

585.626 Biomimetics in Biomedical Engineering
Biomimetics refers to human-made processes, substances, devices, or systems that imitate nature. This course focuses on substances prepared and engineered to meet biomedical uses. It is designed to provide students with: (1) an understanding of the biomimetic process of self-assembly, (2) an introduction to bioengineering biological materials and novel biomimetic materials that include forms and structures useful to bioprocesses, and (3) an understanding of how different instruments may be used for imaging, identification, and characterization of biological and biomimetic materials. Detailed knowledge of biological structure hierarchy is essential for most areas of biomedical engineering, and biological materials are becoming an increasingly important resource in creating new biomimetic materials that possess targeted biological structural and functional properties.

Instructors: Deacon, Trexler

615.441 Mathematical Methods for Physics and Engineering
This course covers a broad spectrum of mathematical techniques essential to the solution of advanced problems in physics and engineering. Topics include ordinary and partial differential equations, contour integration, tabulated integrals, saddle-point methods, linear vector spaces, boundary-value problems, eigenvalue problems, Green's functions, integral transforms, and special functions. Application of these topics to the solution of problems in physics and engineering is stressed.

Prerequisites
Vector analysis and ordinary differential equations (linear algebra and complex variables recommended).

Instructor: Adelmann

615.442 Electromagnetics
Maxwell's equations are derived and applied to the study of topics including electrostatics, magnetostatics, propagation of electromagnetic waves in vacuum and matter, antennas, wave guides and cavities, microwave networks, electromagnetic waves in plasmas, and electric and magnetic properties of materials.

Prerequisites
Knowledge of vector analysis, partial differential equations, Fourier analysis, and intermediate electromagnetics.

Instructor: Awadallah

615.451 Statistical Mechanics and Thermodynamics
After a brief historical review of thermodynamics and statistical mechanics, the basic principles of statistical mechanics are presented. The classical and quantum mechanical partition functions are discussed and are subsequently used to carry out derivations of the basic thermodynamic properties of several different systems. Topics discussed include Planck's black body radiation derivation and the Einstein-Debye theories of the specific heats of solids. The importance of these topics in
the development and confirmation of quantum mechanics is also examined. Other topics discussed include Fermi Dirac and the Bose-Einstein statistics and the cosmic background radiation. The importance of comparisons between theory and data is stressed throughout.

Instructor: Kundu

615.453 Classical Mechanics

This is an advanced course in classical mechanics that introduces techniques that are applicable to contemporary pure and applied research. The material covered provides a basis for a fundamental understanding of not only quantum and statistical mechanics but also nonlinear mechanical systems. Topics include the Lagrangian and Hamiltonian formulation of classical mechanics, Euler's rigid body equations of motion, Hamilton-Jacobi theory, and canonical perturbation theory. These methods are applied to force-free motion of a rigid body, oscillations of systems of coupled particles, and central force motion including the Kepler problem and scattering in a Coulomb potential. Applications are emphasized through in-class examples and homework.

Prerequisites
Intermediate mechanics and 615.441 Mathematical Methods for Physics and Engineering.

Instructor: Freund

615.454 Quantum Mechanics

This is a course in advanced modern physics that presents the basic concepts and mathematical formalism of quantum mechanics and introduces applications in atomic, molecular, and solid-state physics. Topics include the mathematics of quantum mechanics, one-dimensional problems, central field problems, the interaction of electromagnetic radiation with atomic systems, the harmonic oscillator, angular momentum, and perturbation theory.

Prerequisites
615.441 Mathematical Methods for Physics and Engineering or the equivalent.

Instructor: Najmi

615.465 Modern Physics

This course covers a broad spectrum of topics related to the development of quantum and relativity theories. The understanding of modern physics and its applications is essential to the pursuit of advanced work in materials, optics, and other applied sciences. Topics include the special theory of relativity, particle-like properties of light, wavelike properties of particles, wave mechanics, atomic and nuclear phenomena, elementary particles, statistical physics, solid state, astrophysics, and general relativity.

Prerequisites
Undergraduate degree in physics or engineering.

Instructor: Hawkins

615.447 Fundamentals of Sensors and Sensor Systems

Students will receive an overview of sensors and methods to build networks and systems using sensors. The physics of detectors including fundamental technologies and sampling interfaces will be discussed. Sensor technologies for chemical, biological, nuclear, and radiological detection will be studied in detail. Evaluation methods will be presented for sensor selection based on application-specific information including sensor performance, environmental conditions, and operational impact. DODAF 2.0 methods will be taught and a project based on several viewpoints will be required and presented. Additional studies will include methods for combining results from various sensors to increase detection confidence. As part of the course, students will be given a threat scenario and will be required to select a sensor suite and networking information to design a hypothetical system considering the threat, sensor deployment cost, and logistics.

Prerequisites
An undergraduate degree in engineering, physics, or a related technical discipline.

Instructor: Lesho

615.480 Materials Science

This course covers a broad spectrum of materials-related topics designed to prepare the student for advanced study in the materials arena. Topics include atomic structure, atom and ionic behavior, defects, crystal mechanics, strength of materials, material properties, fracture mechanics and fatigue, phase diagrams and phase transformations, alloys, ceramics, polymers, and composites.

Prerequisites
Undergraduate degree in physics or engineering.

Instructor: Charles

Additional Six Courses

Of the remaining six courses, four or more must be from the courses listed below selected from the applied physics, electrical and computer engineering, materials science and engineering, and chemical and biomolecular engineering curricula.

615.481 Polymeric Materials

This is a comprehensive course in polymeric materials. Topics include natural (biological) polymers, polymer synthesis, polymer morphology, inorganic polymers, ionomers, and polymeric materials applications. Composite materials containing polymers will also be discussed. A portion of the course will be devoted to the evaluation of polymer properties by physical methods.

Instructor: Staff

615.746 Nanoelectronics: Physics and Devices

This course provides an introduction to state-of-the-art and potential future electronics technologies. The first part of the course focuses on the physics of advanced silicon technology
and on its scaling limits. The treatment includes a discussion of future electronics as projected to the year 2012 by the Semiconductor Industry Association’s National Technology Roadmap for Semiconductors. This understanding of conventional technology then motivates the second part of the course, which covers some of the “new” physics currently being explored for going “beyond the roadmap.” Topics range from the reasonably practical to the highly speculative and include tunneling transistors, single-flux quantum logic, single-electronics, spin-based electronics, quantum computing, and perhaps even DNA-based computing. An overview is also given of the prospects for advances in fabrication technology that will largely determine the economic viability for any of these possible electronic futures.

**Prerequisites**
625.454 Quantum Mechanics or equivalent; 615.760 Physics of Semiconductor Devices or equivalent.

**Instructor:** Staff

### 615.747 Sensors and Sensor Systems
The primary objective of this course is to present recent advances made in the field of sensors. A broad overview includes radiation, biological, magnetic, fiber optic, and acoustic sensors. The course will examine basic sensor operation and the implementation of sensors in measurement systems. Other topics to be covered are physical principles of sensing, interface electronic circuits, and sensor characteristics. The focus will be on practical application and state-of-the-art developments.

**Instructor:** Fitch

### 615.757 Solid-State Physics
Students examine concepts and methods employed in condensed matter physics with applications in materials science, surface physics, and electronic devices. Topics include atomic and electronic structure of crystalline solids and their role in determining the elastic, transport, and magnetic properties of metals, semiconductors, and insulators. The effects of structural and chemical disorder on these properties are also discussed.

**Prerequisites**
615.454 Quantum Mechanics or the equivalent.

**Instructor:** Charles

### 615.760 Physics of Semiconductor Devices
This course examines the physical principles underlying semiconductor device operation and the application of these principles to specific devices. Emphasis is placed on understanding device operation, rather than on circuit properties. Topics include elementary excitations in semiconductors such as phonons, photons, conduction electrons, and holes; charge and heat transport; carrier trapping and recombination; effects of high doping; contacts; the pn junction; the junction transistor; surface effects; the MIS diode; and the MOSFET.

**Prerequisites**
Mathematics including differential equations and linear operators. Familiarity with quantum mechanics would be helpful.

**Instructor:** Charles
Mechanical Engineering

Mechanical engineering is among the broadest of the engineering disciplines, for it lies at the core of engineering design and engineering practice. Engineering is changing rapidly because of the coupling of globalization with advances in information technology, biomedicine, and nanotechnology, and mechanical engineering is the discipline that is leading this change. From the design of medical prostheses to the cooling of advanced computers, and from robot vision to computer-integrated manufacturing, the scope of mechanical engineering is growing at an accelerating pace. The Mechanical Engineering program at Johns Hopkins seeks to develop engineering professionals who can both strengthen the core of the discipline and lead the profession in a time of rapid change.

The Master of Mechanical Engineering program is designed for practicing engineers who wish to prepare for and enhance their effectiveness in a complex and rapidly evolving technological and organizational environment. The program is designed not only to broaden and strengthen students’ understanding of the traditional fundamentals but also to introduce them to contemporary applications and technologies.

Courses are offered in three basic focus areas: mechanics (either solid mechanics or thermo-fluids), manufacturing, and robotics and controls. The program has sufficient flexibility to allow students to develop some multidisciplinary strength outside of a focus area. In any case, students are expected to coordinate their selection of courses under the guidance of a faculty advisor.

The degree is awarded on the basis of coursework only. No thesis is required. Course offerings are typically structured in two-year cycles.

Program Committee

Andrea Prosperetti
Charles A. Miller Jr.
Distinguished Professor of Mechanical Engineering
Whiting School of Engineering

Mehran Armand
Principal Professional Staff
Applied Physics Laboratory

M.A. Tuve
Associate Research Professor of Mechanical Engineering
Johns Hopkins University
Faculty of Orthopedic Surgery
Johns Hopkins Medicine

Louis L. Whitcomb
Professor of Mechanical Engineering
Whiting School of Engineering

Admission Requirements

Applicants must meet the general requirements for admission to graduate study outlined in this catalog [see Admission Requirements (page 4)]. Each applicant should hold a bachelor’s degree in mechanical engineering or a related field. Prospective students who do not meet these criteria should direct admission inquiries to the program committee. All admissions decisions are made on an individual basis by the program committee.

Course Requirements

The program offers three focus areas: mechanics (either solids or thermo-fluids), manufacturing, and robotics and controls. The following requirements are common to all focus areas. Additional requirements are listed with the course listings for each focus area.

Ten one-term courses, numbered 400 or higher and specifically approved by the advisor, must be completed within a maximum of five years. One of these courses must be an advanced mathematics course, such as 535.441 Mathematical Methods for Engineers. In addition, at least one computationally oriented course is strongly recommended (but not required).

Each focus area has two required courses, and a total of five courses must be chosen from within one focus area. Adding the required mathematics course accounts for six of the 10 required courses. The remaining four courses can be selected from the graduate offerings of any of the full- or part-time engineering programs of the Whiting School of Engineering (including Technical Management). In particular, students focusing in one area in mechanical engineering can take courses offered under any of the other focus areas.

All required courses within a given focus area will typically be available at least once a year; other courses are generally offered once every two years. All course selections, or course changes, must be approved by the student’s advisor. A thesis is not required, nor is knowledge of a foreign language.

Required Advanced Mathematics Course

This advanced mathematics course must be taken in the first semester of the student’s program, unless the advisor explicitly allows the student to do otherwise.

535.441 Mathematical Methods for Engineers

Suggested Computationally Oriented Courses

Computationally oriented courses are available with varying expectations in terms of mathematical background and programming skill. These include:

535.409 Topics in Data Analysis
535.410 Computational Methods of Analysis
535.431 Introduction to Finite Element Methods
535.432 Applied Finite Elements
565.730 Finite Element Methods (offered by Civil Engineering; cannot be counted with 535.431)
Advanced Certificate for Post-Master's Study
This certificate is awarded to students who complete six graduate-level courses beyond the Master's degree in Mechanical Engineering. The program is intended to add depth and breadth to the concentration of the Master's degree or a related one.

All applications are reviewed by the program committee. After admission to the program, each student is assigned an advisor with whom he or she jointly designs a program tailored to individual educational goals.

All six courses must be completed with a grade of B or above. Students must fulfill all the Advanced Certificate course requirements within three years of enrollment in the program.

Course Descriptions
The courses listed with the prefix 535 are offered one night per week, except in the summer semester when, at the discretion of the instructor, courses can meet twice a week for a smaller number of weeks. Courses with the prefix 530 are usually offered during the day as part of the full-time graduate program in mechanical engineering.

All courses have as minimum prerequisites the following: undergraduate engineering courses in calculus, differential equations, statics, dynamics, thermodynamics, and strength of materials. In addition, the specific prerequisites for each course must be fulfilled.

Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

I. Mechanics Focus Area
Within the Mechanics focus area, students may choose either a Solid Mechanics track or a Thermo-Fluid Mechanics track. Students taking the Solid Mechanics track must take 535.406 Advanced Strength of Materials and 535.423 Intermediate Vibrations. Students taking the Thermo-Fluid Mechanics track must take 535.421 Intermediate Fluid Dynamics and 535.433 Intermediate Heat Transfer. Three additional courses must be chosen from either track (not necessarily all from the same track). The only restriction is that course prerequisites be fulfilled in all cases.

Solid Mechanics Track
535.406 Advanced Strength of Materials
\* Required course for Solid Mechanics track.
535.409 Topics in Data Analysis
535.412 Intermediate Dynamics
535.423 Intermediate Vibrations
\* Required course for Solid Mechanics track.
535.427 Computer-Aided Design
535.431 Introduction to Finite Element Methods
\* Cannot be counted together with 560.730.
535.432 Applied Finite Elements
535.454 Theory and Applications of Structural Analysis

Thermo-Fluid Mechanics Track
535.409 Topics in Data Analysis
535.414 Fundamentals of Acoustics
535.421 Intermediate Fluid Dynamics
\* Required course for Thermo-Fluid Mechanics track.
535.424 Energy Engineering
535.433 Intermediate Heat Transfer
\* Required course for Thermo-Fluid Mechanics track.
535.434 Applied Heat Transfer
535.450 Combustion
535.452 Thermal Systems Design and Analysis
535.461 Energy and the Environment
535.636 Applied Computational Fluid Mechanics
535.712 Applied Fluid Dynamics
585.609 Cell Mechanics
585.618 Biological Fluid and Solid Mechanics

Note: 535.424, 535.443, 535.453, and 535.636 are only occasionally offered.

II. Manufacturing Focus Area
The required courses for the Manufacturing focus area are 535.428 Computer-Integrated Design and Manufacturing and 535.459 Manufacturing Systems Analysis. Three additional courses must be chosen from within the Manufacturing focus area. Course prerequisites must be fulfilled in all cases.

535.423 Intermediate Vibrations
535.426 Kinematics and Dynamics of Robots
535.427 Computer-Aided Design
535.428 Computer-Integrated Design and Manufacturing
\* Required course for Manufacturing focus area.
535.433 Intermediate Heat Transfer
535.442 Control Systems for Mechanical Engineering Applications
535.458 Design for Manufacturability
535.459 Manufacturing Systems Analysis
\* Required course for Manufacturing focus area.
535.460 Precision Mechanical Design
535.472 Advanced Manufacturing Systems
III. Robotics and Controls Focus Area

The required courses for the Robotics and Control focus area are 535.426 Kinematics and Dynamics of Robots and 535.442 Control Systems for Mechanical Engineering Applications. Three additional courses must be chosen from within the Robotics and Controls focus area. Course prerequisites must be fulfilled in all cases.

- 525.409 Continuous Control Systems
- 525.763 Applied Nonlinear Systems
- 535.409 Topics in Data Analysis
- 535.412 Intermediate Dynamics
- 535.427 Computer-Aided Design
- 535.428 Computer-Integrated Design and Manufacturing
- 535.444 Control Systems for Mechanical Engineering Applications
- 535.445 Digital Control and Systems Applications
- 535.459 Manufacturing Systems Analysis
- 535.460 Precision Mechanical Design
- 535.625 Advanced CAD Modeling, Analysis, and Manufacturing
- 535.726 Robot Control

Course Descriptions

535.406 Advanced Strength of Materials
This course reviews stress and strain in three dimensions, elastic and inelastic material behavior, and energy methods. It also covers use of the strength of materials approach to solving advanced problems of torsion, bending of beams and plates, buckling of columns, stress concentrations, and fracture mechanics. The use of finite element analysis in solving problems in mechanics will be introduced as well.

Prerequisite
Required course for Solid Mechanics track.

Instructor: Burkhardt

535.409 Topics in Data Analysis
This course will provide a survey of standard techniques for the extraction of information from data generated experimentally and computationally. The approach will emphasize the theoretical foundation for each topic followed by applications of each technique to sample experimental data. The student will be provided with implementations to gain experience with each tool to allow the student to then quickly adapt to other implementations found in common data analysis packages. Topics include uncertainty analysis, data fitting, feed-forward neural networks, probability density functions, correlation functions, Fourier analysis and FFT procedures, spectral analysis, digital filtering, and Hilbert transforms. Projects will require some programming experience or familiarity with tools such as MATLAB.

Instructor: Hess

535.410 Computational Methods of Analysis
This course serves as an introduction to using MATLAB for typical engineering analyses and may serve as a valuable precursor to the more computationally intensive courses in the program that use MATLAB. Course topics include an introduction to script programming, solution of one- and two-dimensional definite integrals, solution of coupled sets of ordinary differential equations, typical data analysis (e.g., Fourier transforms, curve fitting, and signal processing), and matrix manipulation (e.g., solution of linear systems and eigenvalue extraction).

Instructor: Staff

535.411 Structural Dynamics and Stability
This course introduces the propagation of elastic waves and the loss of stability in engineering structures and systems. In the first part of the course, fundamental physical principles of elasticity and wave mechanics are reviewed and developed to provide students with the capability to model and analyze wave propagation, reflection, and refraction in isotropic and anisotropic engineering structures such as rods, beams, and plates. In the second part of the course, mechanical stability models are studied and applied in terms of dynamic behavior where the combined effects of vibration, gyroscopic motion, impact/shock, and buckling lead to new structural configurations or unstable motions that must often be avoided in design. Applications span nondestructive evaluation, composites, cables, aircraft/space structures, rotordynamics, aeroelasticity, civil engineering structures, and others.

Instructor: Stanton

535.412 Intermediate Dynamics
This course covers kinematics and dynamics of systems of particles and rigid bodies undergoing planar and general 3D motion. Applications of the conservation equations are reviewed in the context of mass-flow and impact. Vectoral and analytical mechanics approaches are introduced and used to analyze the dynamics of systems of interconnected rigid bodies. MATLAB is used as a computational and plotting tool.
throughout the course. The course provides a balance between the underlying theory and real-world problem solving.

**Prerequisite**
An undergraduate dynamics course.

**Instructor:** Stanton  
**When Offered:** Fall

**535.414 Fundamentals of Acoustics**
This course provides an introduction to the physical principles of acoustics and their application. Fundamental topics include the generation, transmission, and reception of acoustic waves. Applications covered are selected from underwater acoustics, architectural acoustics, remote sensing, and nondestructive testing.

**Prerequisites**
Some familiarity with linear algebra, complex variables, and differential equations.

**Instructor:** Burkhardt

**535.421 Intermediate Fluid Dynamics**
This course prepares the student to solve practical engineering flow problems and concentrates on the kinematics and dynamics of viscous fluid flows. Topics include the control volume and differential formulations of the conservation laws, including the Navier–Stokes equations. Students examine vorticity and circulation, dynamic similarity, and laminar and turbulent flows. The student is exposed to analytical techniques and experimental methods, and the course includes an introduction to computational methods in fluid dynamics. It also includes a programming project to develop a numerical solution to a practical fluid flow problem.

**Prerequisite**
An undergraduate fluid mechanics course.

**Instructor:** Hess  
**When Offered:** Fall

**535.422 Robot Motion Planning**
This course investigates the motion planning problem in robotics. Topics include motion of rigid objects by the configurations space and retraction approaches, shortest path motion, motion of linked robot arms, compliant motion, coordinated motion of several objects, robust motion with error detection and recovery, and motion in an unknown environment.

**Instructor:** Kutzer  
**When Offered:** Fall

**535.423 Intermediate Vibrations**
Course topics include transient and forced vibration of one- and N-degree of freedom systems and an introduction to vibration of continuous systems. Hamilton’s Principle and Lagrange’s equations are used throughout the course to derive the equation(s) of motion. MATLAB is introduced and used to solve the equations of motion and plot the response of the system. This course also addresses common topics in applied vibrations such as the environmental testing, the shock response spectrum, random vibration, vibration isolation, and the design of tuned-mass damper systems.

**Prerequisite**
An undergraduate vibrations course. Required course for Solid Mechanics track.

**Instructor:** Stanton  
**When Offered:** Spring

**535.424 Energy Engineering**
The course will focus on an analytical system performance technique known as Availability or Exergy Analysis, which is based on the second law of thermodynamics. The course focuses on traditional power and refrigeration systems. However, nontraditional power generation systems will be considered by way of a special project of each student’s choice. It will include an engineering description of the state of the art of the selected topic (e.g., wind or solar power, fuel cell, etc.), and a second law performance analysis of a prototype system will be presented to the class. In addition to the power system topics, the availability analysis will be applied to the combustion and psychrometric processes.

**Instructor:** Staff  
**Offered only occasionally.**

**535.426 Kinematics and Dynamics of Robots**
This course introduces the basic concepts and tools used to analyze the kinematics and dynamics of robot manipulators. Topics include kinematic representations and transformations, positional and differential kinematics, singularity and workspace analysis, inverse and forward dynamics techniques, and trajectory planning and control.

**Instructor:** Armand  
**When Offered:** Fall

**535.427 Computer-Aided Design**
This course provides a wide-ranging exploration of computer-aided design (CAD) using Creo Parametric (a PTC CAD software, previously called Pro/ENGINEER). Topics include sketching, solid modeling, assembly modeling, detail drafting, geometric dimensioning and tolerancing, advanced modeling, sheet metal modeling, mechanism dynamics, and structural/thermal finite element analysis (FEA).

**Instructor:** Boyle  
**When Offered:** Fall and Spring

**535.428 Computer-Integrated Design and Manufacturing**
This course emphasizes the computer automation of design and manufacturing systems. A survey of the automation techniques used in modern design and manufacturing facilities is presented. Discussions are presented related to the system integration of computer-aided design (CAD), computer-
aided engineering (CAE), computer-aided manufacturing (CAM), robotics, material resource planning, tool management, information management, process control, and quality control. The current capabilities, applications, limitations, trends, and economic considerations are stressed.

Instructor: Ivester
When Offered: Spring

535.431 Introduction to Finite Element Methods
Topics covered by this course include theory and implementation of finite element models for typical linear problems in continuum mechanics including fluid flow, heat transfer, and solid mechanics. Emphasis will be placed on developing a fundamental understanding of the method and its application.

Course Notes
Cannot be counted with 560.730.

Instructor: Lear

535.432 Applied Finite Elements
This course provides an introduction to the study of mechanics using the finite element method. Topics include the stiffness method, stationary principles, the Rayleigh–Ritz method, displacement-based elements, isoparametric formulation, and coordinate transformation. A general-purpose finite element analysis package will be used for computer project assignments. Students who successfully complete this course will be able to utilize general purpose commercial code to solve linear two- and three-dimensional problems in statics and vibrations.

Instructor: Staff

535.433 Intermediate Heat Transfer
This course covers the following topics: transient heat conduction, forced and free convection in external and internal flows, and radiation processes and properties.

Prerequisite
An undergraduate heat transfer course.

Instructor: Green
When Offered: Spring

535.434 Applied Heat Transfer
This course focuses on the inevitable tradeoffs associated with any thermodynamic or heat transfer system, which result in a clear distinction between workable and optimal systems. The point is illustrated by means of a number of concrete problems arising in power and refrigeration systems, electronics cooling, distillations columns, heat exchange, and cogeneration systems.

Prerequisite
An undergraduate heat transfer course.

Instructor: Healy

535.441 Mathematical Methods for Engineers
This course covers a broad spectrum of mathematical techniques needed to solve advanced problems in engineering.

Topics include linear algebra, the Laplace transform, ordinary differential equations, special functions, partial differential equations, and complex variables. Application of these topics to the solutions of physics and engineering problems is stressed.

Prerequisites
Vector analysis and ordinary differential equations. This course may be substituted for 615.441 Mathematical Methods for Physics and Engineering in the Applied Physics program.

Instructor: Nakos
When Offered: Spring and Fall

535.442 Control Systems for Mechanical Engineering Applications
This class provides a comprehensive introduction to the theory and application of classical control techniques for the design and analysis of continuous-time control systems for mechanical engineering applications. Topics include development of dynamic models for mechanical, electrical, fluid-flow and process-control systems, introduction to Laplace transforms, stability analysis, time and frequency domain analysis techniques, and classical design methods. The class will use a series of applications that build in complexity throughout the semester to emphasize and reinforce the material.

Instructor: Urban
When Offered: Spring

535.445 Digital Control and Systems Applications
This class will provide a comprehensive treatment of the analysis and design of discrete-time control systems. The course will build upon the student’s knowledge of classical control theory and extend that knowledge to the discrete-time domain. This course is highly relevant to aspiring control systems and robotics engineers since most control system designs are implemented in micro-processors (hence the discrete-time domain) vice analog circuitry. Additionally, the course will go into advanced control system designs in the state-space domain and will include discussions of modern control design techniques including linear-quadratic optimal control design, pole-placement design, and state-space observer design. The class will use a series of applications that build in complexity throughout the semester to emphasize and reinforce the material.

Prerequisite
535.442 Control Systems for Mechanical Engineering Applications.

Instructor: Urban

535.450 Combustion
This is a multidisciplinary course involving applications of thermodynamics, fluid mechanics, heat transfer, and chemistry. Course contents include a review of chemical thermodynamics, chemical kinetics, transport theory, and conservation equations; laminar flow in premixed and non-premixed gases; combustion waves; ignition; combustion aerodynamics; mul-
tiphase combustion; and turbulent combustion. Selected applications are discussed including gas turbines, spark ignition and diesel engines, jet engines, industrial furnaces, pollutant formation, and control in combustion.

Prerequisites
Undergraduate-level exposure to thermodynamics, fluid dynamics, differential equations, and basic chemistry.

Instructor: Kweon

535.452 Thermal Systems Design and Analysis
Thermodynamics, fluid mechanics, and heat transfer principles are applied using a systems perspective to enable students to analyze and understand how interactions between components of piping, power, refrigeration, and thermal management systems affect the performance of the entire system. Following an overview of the fundamental principles involved in thermal and systems analyses, the course will cover mathematical methods needed to analyze the systems and will then explore optimization approaches that can be used to improve designs and operations of the thermal systems to minimize, for example, energy consumption or operating costs.

Prerequisites
Undergraduate courses in thermodynamics and heat transfer. No computer programming is required.

Instructor: Healy

535.454 Theory and Applications of Structural Analysis
This is a course in classical plate and shell structures with an emphasis on both analysis and application. Both differential and energy method approaches are presented. Topics include an introduction to thin plate theory, its application to circular and rectangular plates, buckling, and thermal effects. Classical thin shell theory is also presented. Applications to common plate and shell structures are discussed throughout.

Instructor: Burkhard

535.458 Design for Manufacturability
The key principles for designing a quality, cost-efficient product are related to competitiveness in manufacturing environments in this course. Topics include design for manufacturing, design for assembly, process selection, inspection planning, concurrent engineering, product re-engineering, quality management, and agile manufacturing. The focus is on engineering designs and system approaches that affect cost, quality, cycle time, and maintainability.

Instructor: Ivester

535.459 Manufacturing Systems Analysis
This course is a review of the fundamentals of modern manufacturing processes, computer-aided design/manufacturing tools, flexible manufacturing systems, and robots. The course addresses relationships between process machinery, process conditions, and material properties. Examples of high-tech industries illustrate how mechanical and electronic components are manufactured from metals, polymers, ceramics, composites, and silicon.

Instructor: Ivester

When Offered: Fall

535.460 Precision Mechanical Design
This course will provide the student with a fundamental understanding of the principles and techniques used to design precision machines, instruments, and mechanisms. Lectures will include discussions on the implementation and design of mechanisms, bearings, actuators, sensors, structures, and precision mounts used in precision design. Upon completion of this course, students will have a clear understanding of positional repeatability and accuracy, deterministic design, exact constraint design, error modeling, and sources of machine and instrumentation errors.

Instructor: Fesperman

535.461 Energy and the Environment
The course focuses on advanced topics related to energy and thermodynamics. The objective of this course is to provide a thorough understanding of the environmental impacts related to energy conversion systems. The use of the second law of thermodynamics is introduced to quantify the performance of energy conversion systems. Topics such as global warming, alternative energy sources (solar, wind power, geothermal, tides, etc.), new technologies (fuel cells and hydrogen economy), and resources and sustainable development are addressed. A section of the course is devoted to current trends in nuclear energy generation and associated environmental issues.

Prerequisite
Undergraduate-level exposure to thermodynamics.

Instructor: Herman

535.472 Advanced Manufacturing Systems
This course examines the effect that new technology, engineering, and business strategies have on transforming U.S. industry into a world-class, competitive force. An emphasis is placed on the state-of-the-art of factory automation and computer-integrated manufacturing. Topics include advanced manufacturing processes, rapid prototyping, intelligent manufacturing controls, and information technology in manufacturing. Technical principles related to advanced manufacturing are presented. Examples of actual production systems (including video presentations and plant visits) illustrate how industry is adopting the latest technology to meet customer requirements for quality, low cost, and flexibility.

Instructor: Ivester

535.625 Advanced CAD Modeling, Analysis, and Manufacturing
This course presents advanced mechanical design techniques using the Pro/ENGINEER CAD/CAM software. It explains
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advanced methods and techniques about assembly management and mechanism design, kinematic and dynamic analyses, structural analyses (FEA), and CNC manufacturing. The material is presented based on extensive hands-on examples. The CAM section includes practical examples with three- to five-axis Vertical Machining Centers (HAAS FV-1&2) and a Turning CNC center (HAAS SL-20).

Prerequisite
Knowledge and experience with basic ProE parts and assembly management.

Instructor: Stoianovici

535.626 Advanced Machine Design
This course provides a broad treatment of stress, strain, and strength with reference to engineering design and analysis. Major emphasis is placed on the analytical and experimental methods of determination of stresses in relationship to the strength properties of machine elements under various loading conditions. Also considered are deflection, post-yield behavior, residual stresses, thermal stresses, creep, and extreme temperature effects as applied to the design of fasteners, shafts, power trains, and rotational machinery.

Instructor: Dehghani

535.636 Applied Computational Fluid Mechanics
This course explores engineering applications of computational fluid dynamics with background information on the most common numerical methods: two-dimensional inviscid and viscous flows, boundary layer flows, and an introduction to three-dimensional flows. Applications are illustrated utilizing commercially available codes.

Prerequisites
535.421 Intermediate Fluid Dynamics and 535.441 Mathematical Methods for Engineers. Some programming experience is also assumed.

Instructor: Staff
Offered only occasionally.

535.637 Multiscale Modeling and Simulation of Mechanical Systems
Successfully designing complex engineering systems requires understanding mechanical processes that bridge multiple length and time scales. This course will introduce students to the field of multiscale modeling and provide a foundation for understanding systems/devices at a molecular, microscopic, and macroscopic level. Through a combination of lectures, case studies, and hands-on applications, students will learn (1) the principles that govern engineering systems at various length and time scales, and (2) how to use/develop multiscale mechanical modeling and simulation tools.

Instructor: Thomas

535.712 Applied Fluid Dynamics
This course will provide a survey of topics in applied fluid dynamics for the practicing engineer. The first topic will concentrate on pipe and duct flow, looking at friction factors, abrupt changes in area, and pipe systems. This is followed by unsteady flows focusing on pressure transients, such as the water hammer. A section on lubrication theory covering wedge and journal bearings is presented. Open channel flows are discussed with emphasis on optimum cross-sectional shape and specific energy. Turbomachinery such as axial and centrifugal pumps, including specific speed and suction limitations, is described. Fluid dynamic drag and lift from streamlined surfaces are presented, including topics such as vortex shedding, terminal velocity, and cavitation. The approach will emphasize the practical foundation needed to solve real-world problems.

Prerequisite
535.421 Intermediate Fluid Dynamics. Projects will require some programming experience or familiarity with tools such as MATLAB.

Instructor: Hess

535.720 Analysis and Design of Composite Structures
Topics in this course include anisotropic elasticity, laminate analysis, strength of laminates, failure theories, bending, buckling, and vibration of composite plates. The second part of the course is devoted to the applications of the structural analysis of composite structures by means of finite-elements computer codes.

Instructor: Staff

535.726 Robot Control
This course focuses on the theory and methods used for the control of robotic manipulators. Topics include review of basic systems theory, robot position control, model-based trajectory tracking, and force control. Stability properties for each control strategy will be analyzed. Practical implementation issues will also be addressed. Students will simulate different control methods using MATLAB.

Prerequisites
535.426 Kinematics and Dynamics of Robots, Ordinary Differential Equations, Linear Algebra.

Instructor: Armand

535.731 Engineering Materials: Properties and Selection
Become familiar with different classes of engineering materials and their tradeoffs associated with design criteria such as strength, toughness, corrosion resistance, and fabricability, as well as some common test methods for evaluating material properties. This course will concentrate on metal alloys but will also consider polymers and ceramics. Topics specific to metals will include effects of work hardening and heat treatment, corrosion, and elevated temperature properties.
Topics specific to polymers will include viscoelasticity, stress relaxation and creep, and phase transitions. Topics specific to ceramics will include flaw-dominated strength, fracture energy, and statistical determination of strength. The course also includes an introduction to the Ashby method of material selection and optimization.

**Instructor:** Lennon

**When Offered:** Spring
Systems Engineering

The systems engineering process coordinates and oversees the translation of an operational need into a system designed to meet that need. It integrates the inputs of all the required technical disciplines into a coordinated effort that meets established performance, cost, and schedule goals. Systems engineers provide the leadership and coordination of the planning, development, and engineering of technical systems, including hardware and software components.

The JHU Systems Engineering program provides professionals with in-depth knowledge and technical skills in the field of systems engineering and systems of systems, and prepares students for careers within industry and government. The program addresses the needs of engineers and scientists engaged in all aspects of analysis, design, integration, production, and operation of modern systems. Instructors are practicing systems engineers who employ lectures and readings on theory and practice and present realistic problem scenarios in which students, individually and collaboratively, apply principles, tools, and skills. Two master's degree distinctions are offered by the JHU Systems Engineering program: the Master of Science (MS) in Systems Engineering and the Master of Science in Engineering (MSE) in Systems Engineering. There is no curricular difference between the two programs—both degrees can be earned by completing the same coursework. The only difference is the undergraduate degree with which the student enters. The MSE in Systems Engineering will be awarded to those with ABET-accredited undergraduate degrees, while the MS in Systems Engineering will be awarded to students with different qualifications upon entry. Details for both programs can be found below.

Master of Science in Engineering (MSE) in Systems Engineering

The JHU Systems Engineering program offers students and their employers the highest-quality graduate education in the field. Students who are admitted with a transcript from an accredited undergraduate ABET EAC (Engineering Accreditation Commission) program (abet.org) will be awarded a MSE in Systems Engineering upon completion of the JHU requirements.

The program educational objectives of the MSE program are as follows: (1) attain programmatic or technical leadership roles in an organization identifying, formulating, designing, and/or testing practical solutions to engineering problems and guide the engineering development of modern complex systems; and (2) employ systems engineering methods and tools in the development of advanced complex systems.

Undergraduates from an ABET EAC-accredited program will have as part of their prior academic experience:

A. One year of a combination of college-level mathematics and basic sciences (some with experimental experience) appropriate to the discipline. Basic sciences are defined as biological, chemical, and physical sciences.

B. One and a half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study. The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other. Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative) in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.

C. A general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives.

Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier coursework and incorporating appropriate engineering standards and multiple realistic constraints.

Master of Science (MS) in Systems Engineering

Consistent with the INCOSE (International Council of Systems Engineering) Graduate Reference Curriculum for Systems Engineering (GRCSE), and the view that systems engineering is interdisciplinary, the JHU MS in Systems Engineering program provides a broad common framework for students coming from a wide variety of undergraduate backgrounds, including engineering, sciences, mathematics, management, business, or computer science. Students who do not have an accredited undergraduate ABET EAC degree will be awarded an MS in Systems Engineering degree upon completion of the JHU program requirements. Applicants should have at least one year of practical systems experience and a demonstrated ability to effectively communicate technical information, both orally and in writing.

Program Committee

Ronald R. Luman, Chair
Principal Professional Staff
Applied Physics Laboratory

Samuel J. Seymour, Vice Chair
Principal Professional Staff
Applied Physics Laboratory

Larry D. Strauser, Vice Chair
Principal Professional Staff
Applied Physics Laboratory

Steven M. Biemer
Principal Professional Staff
Applied Physics Laboratory

William B. Crownover
Principal Professional Staff
Applied Physics Laboratory
General Admission Requirements for MSE or MS in Systems Engineering

Applicants must meet the JHU general requirements for admission to a graduate program outlined in this catalog [see Admission Requirements (page 4)]. Systems engineering master's degree candidates holding a degree in a technical field from a regionally accredited and ABET Engineering Accreditation Commission (EAC)-accredited college or university will be considered for the Master of Science in Engineering degree. Students admitted without an ABET EAC-accredited BS or who did not complete the prerequisites to meet ABET EAC-accredited math, science, and engineering design requirements at the BS level will receive a regionally accredited Master of Science degree.

Admission decisions will be made by focus area. In addition, the applicant should have a minimum of one year of appropriate full-time work experience in that field. A résumé must be submitted with the application form. In considering applications to the Systems Engineering program, both academic record and experience will be considered and, at the discretion of the Admissions Committee, years and quality of experience may compensate for a GPA that is short of the required 3.0. Academic standards governing graduate study, as specified in this catalog, must be maintained. Knowledge of a foreign language is not required in these programs. A total of 10 one-semester courses must be completed within five years.

Systems Engineering—Online

Both systems engineering master's degrees can be completed online. Online course content is identical to that in the classrooms but available in a paced, asynchronous mode over the Internet. Recorded lectures with associated multimedia content are augmented with online discussions and weekly synchronous office hours. This increases the flexibility of course offerings for students wishing to pursue studies in either the on-site or online format, or a combination of both.

Prospective and current students should consult the EP website for the most current online course offerings, course schedules, and procedures for online programs. The online courses are available only in the Systems Engineering, Cybersecurity, Software Systems, Project Management, Modeling and Simulation, and Human Systems Engineering focus areas.

Systems Engineering Core Courses

All Systems Engineering graduate students must complete 10 one-semester courses to earn either the MSE or MS in Systems Engineering degree. There are five core Systems Engineering courses that are required for all focus areas:

- 645.462 Introduction to Systems Engineering
- 645.467 Management of Systems Projects
- 645.767 System Conceptual Design
- 645.768 System Design and Integration
- 645.769 System Test and Evaluation

Systems Engineering Focus Areas

Students pursuing the MSE or MS in Systems Engineering may elect to concentrate their studies in one of several focus areas listed below for only those focus areas that they have been admitted.

Systems Engineering Focus Area

Systems Engineering focus area students must meet the general admissions requirements and satisfactorily complete 10 one-semester courses. In addition to the five core courses, students must also complete:

Required course:

- 645.764 Software Systems Engineering

One of the following four advanced courses (after taking the five core courses):

- 645.742 Management of Complex Systems
- 645.753 Enterprise Systems Engineering
- 645.761 Systems Architecting
- 645.771 System of Systems Engineering

Master's Project or Thesis

Students must complete either the one-semester Systems Engineering Master's Project or the two-semester Systems Engineering Master's Thesis. The thesis option is strongly recommended only for students planning to pursue doctoral studies.

- 645.800 Systems Engineering Master's Project
- 645.801/802 Systems Engineering Master's Thesis

Electives

Systems Engineering focus area students must complete one or two relevant electives, depending on whether the student has selected the master's project or the master's thesis option, respectively. Electives may be selected from the Technical Management, Applied Biomedical Engineering, Applied
Physics, Computer Science, Electrical Engineering, Environmental Engineering and Science, and Information Systems Engineering programs.

Systems engineering students may not take the following as elective courses:

- 595.460 Introduction to Project Management
- 595.464 Project Planning and Control I
- 595.763 Software Engineering Management

There are two additional Systems Engineering courses that may serve as electives:

- 645.469 Systems Engineering of Deployed Systems
- 645.756 Metrics, Modeling, and Simulation for Systems Engineering

**Project Management Focus Area**

The systems engineer and program/project manager must work as a team to develop a product and to organize and execute a complex project. The systems engineer helps create the statement of work, work breakdown structure, schedule, and budget consistent with the technical requirements and the risks of the project. In order to improve communications and understanding of the program and project manager roles and tools, and to develop needed leadership skills, the Project Management focus area provides a system view of the management of a technical project.

Project Management focus area students must meet the general admission requirements and satisfactorily complete 10 one-semester courses including the five core courses. They must also complete:

**Required courses:**

- 595.461 Technical Group Management
- 645.764 Software Engineering Management
- 645.800 Systems Engineering Master’s Project **AND**
- 595.465 Communications in Technical Organizations **OR**
- 595.466 Financial and Contract Management

**One of the following four advanced courses:**

- 645.742 Management of Complex Systems
- 645.753 Enterprise Systems Engineering
- 645.761 Systems Architecting
- 645.771 System of Systems Engineering

**Biomedical Systems Engineering Focus Area**

Systems engineering is playing an increasing role in the development and implementation of modern complex biomedical systems. If today’s practicing engineers and scientists are to develop new and much-needed biomedical technologies and systems, they need to plan, coordinate, and oversee interdisciplinary teams whose efforts translate operational needs into technology solutions and whose tools and skills determine whether a system will meet cost, schedule, and performance goals. At the same time, they should understand the fundamental nature and interaction of biological and physiological systems.

This focus area trains students to integrate the diverse areas of biomedical engineering with the skills and tools of a systems engineer. Students should expect they will have a deeper understanding of the field and a broader perspective of the system challenges of biomedical systems that they will be able to immediately implement in their places of employment. Biomedical Systems Engineering focus area students must meet the general admission requirements and, in addition, have taken mathematics through ordinary differential equations, calculus-based physics, and organic and inorganic chemistry. Biomedical work experience is desired. Students must satisfactorily complete 10 one-semester courses including the five core courses. They must also complete:

**Required course:**

- 645.805 Biomedical Systems Engineering Master’s Project

**Three Biomedical Core Courses**

The following additional required biomedical courses are offered at the Applied Physics Laboratory or the Dorsey Center:

- 585.405 Physiology for Applied Biomedical Engineering I
- 585.406 Physiology for Applied Biomedical Engineering II
- 585.409 Mathematical Methods for Applied Biomedical Engineering

**One Elective Course**

Biomedical Systems Engineering students are required to take an elective course selected from the following with advisor approval. Please note that courses prefixed by 580 are offered at the Homewood campus in Baltimore (often in the daytime).

- 580.630 Theoretical Neuroscience
- 580.644 Neural Control of Movement and Vocalization
- 580.651 Introduction to Nonlinear Dynamics in Physiology
- 580.702 Neuroengineering Seminar
- 585.408 Medical Sensors and Devices
- 585.608 Biomaterials
- 585.611 Practices of Biomedical Engineering
- 585.614 Applications of Physics and Technology to Biomedicine
- 585.626 Biomimetics in Biomedical Engineering
- 585.634 Biophotonics

**Human Systems Engineering Focus Area**

Human systems engineering (HSE) is a comprehensive program for considering the requirements and constraints of humans as part of an overall system solution. Systems engineering addresses the three major components of a system:
hardware, software, and humans. A total systems approach that considers all three components and the complex interactions among them has been recognized as essential by government and industry organizations responsible for system development and operation. Failure to consider the human component in systems engineering can lead to less effective system performance and even to catastrophic failure.

Human systems engineering involves factors from many domains, including human capabilities and limitations; human performance measurement and analysis; integrating people and technology; system use in complex operational situations; and the influence of environmental, organizational, and social factors on system requirements and design. These factors play a role throughout the system life cycle; they are involved in determining requirements, allocating functions, system and component design, testing and evaluation, training, and system sustainment.

The Human Systems Engineering focus area trains students in the human systems integration domains and their interdependencies as well as provides additional material related to general human systems engineering. Students will gain a deeper understanding of how the appropriate application of human systems engineering adds value to systems, and they will graduate with knowledge of the human component and keen judgment to know how to incorporate human systems engineering.

Human Systems Engineering focus area students must meet the general admission requirements and satisfactorily complete 10 one-semester courses. The curriculum consists of the five required core courses in systems engineering, two core HSE focus area courses, two HSE electives, and the completion of a Systems Engineering Master’s Project with a Human Systems Engineering focus.

**Required course:**

645.808 Human Systems Engineering Master’s Project

**Two human systems engineering core courses:**

645.450 Foundations of Human Systems Engineering

645.451 Integrating Humans and Technology

**Two of the following three human systems engineering elective courses:**

635.461 Principles of Human-Computer Interaction

645.754 Social and Organizational Factors in Human Systems Engineering

645.755 Methods in Human-System Performance Measurement and Analysis

**Cybersecurity Systems Engineering Focus Area**

Systems engineering methodologies are required to develop, evaluate, protect, and maintain highly integrated and complex information systems to ensure these systems are able to work together effectively and efficiently in the face of increasing threats and advancing technologies. When sophisticated attempts are made to exploit weaknesses in information systems, attention is required in the computing environments, the supporting infrastructure, and the boundaries and interfaces of their networks. A systems approach to the security architecture, design, development, and testing of information systems will address cyber security requirements to control access, protect assets, validate security subsystems, train users, and manage systems.

The cyber security operations protect and defend information and information systems to ensure their availability, integrity, authentication, confidentiality, and non-repudiation. Cyber security provides for restoration of information systems by incorporating protection, detection, and reaction capabilities focused on risk management to address threats using a cost-effective approach in the context of the environment of the fielded systems. Using systems engineering techniques and methodologies are employed to determine where vulnerabilities might exist, modeling and simulation to determine tradeoffs in the protection of systems, and a variety of techniques for the creation of systems that protect and defend information systems. This concentration trains students to integrate the diverse areas of cyber security with the skills and tools of a systems engineer and a computer scientist. Students will gain a deeper understanding of the field and a broader perspective of the system challenges, which they will be able to immediately implement on the job.

Cybersecurity Systems Engineering focus area students must meet the general admission requirements and in addition have taken mathematics through integral calculus, a course in computer programming, and a computer networking or structures course. The curriculum consists of the five required core courses in Systems Engineering, two required courses in Cybersecurity, two elective courses in Cybersecurity, and the completion of a Systems Engineering Master’s Project with a cyber security focus.

**Required course:**

645.806 Cybersecurity Systems Engineering Master’s Project

**Two Cybersecurity core courses:**

695.401 Foundations of Information Assurance

695.721 Network Security

**Two elective courses from the following three courses:**

695.421 Public Key Infrastructure and Managing E-Security

695.422 Web Security

695.791 Information Assurance Architectures and Technologies
Modeling and Simulation Systems Engineering Focus Area

One of the most important tools in systems engineering is the use of modeling and simulation processes to help elicit system requirements, support the analysis of alternatives, estimate and optimize cost and schedule, predict system performance, and to improve systems processes. Models and simulations help perform experiments that may not be possible in the real world due to physical, environmental, or economic constraints.

Modeling and simulation should be used to support engineering activities throughout the full systems life cycle. From concept, design, and testing to evaluating product performance, model-based tools provide the means for experimentation and analysis to better understand the attributes and expected behavior of the system and to evaluate the processes and strategies needed to optimize the system performance. M&S also accounts for human systems integration, manufacturability, and sustaining the product.

Modeling and Simulation Systems Engineering focus area students must meet the general admission requirements and also have taken mathematics through multivariate calculus and statistics, a course in computer programming, and a computer networking or structures course. The curriculum consists of the five Systems Engineering core courses, followed by a rigorous course in statistical methods and data analysis. This latter course from the Applied and Computational Mathematics program provides an understanding of statistical techniques and the use of several methodologies for practical world problems. Two additional required courses provide the use of modeling and simulation following the systems engineering life cycle and experience in advanced modeling and simulation topics including verification, validation, and accreditation; markup languages; cost modeling; simulation interoperability; and collaborative environments. Students are also required to take the two-semester systems engineering master’s thesis course that will lead to a publication.

Required courses:
645.801/802 Systems Engineering Master’s Thesis

Three modeling and simulation core courses:
625.403 Statistical Methods and Data Analysis
645.757 Foundations of Modeling and Simulation in Systems Engineering
645.758 Advanced Systems Modeling Simulation

Software Systems Engineering Focus Area

Systems engineers are increasingly responsible for developing software-intensive systems. This concentration provides the fundamental knowledge and skills required for specifying and implementing a system development, combined with the competencies needed to define and document software requirements, analyze and design software systems, and manage the software project activities. Following the core systems engineering courses, software courses emphasize structural and design techniques, software safety, software project cost and schedule estimation, and techniques for evaluating software maturity and efficiency.

This concentration will provide systems engineers with the knowledge of software engineering and management to improve their effectiveness with systems development that includes significant software components. Teamwork and group projects are emphasized throughout the curriculum to prepare students for real-life work environments.

Software Systems Engineering focus area students must meet the general admission requirements and also have taken mathematics through integral calculus, a course in computer programming, and a computer networking or structures course. The curriculum consists of five required core courses in systems engineering, three required courses in software systems, one elective course in software systems, and completion of the Systems Engineering Master’s Project with a Software Systems focus.

Four required courses:
605.401 Foundations of Software Engineering
605.402 Software Analysis and Design
605.708 Tools and Techniques of Software Project Management
645.807 Software Systems Engineering Master’s Project

One elective course from the following three courses:
605.407 Agile Software Development Methods
605.701 Software Systems Engineering
605.705 Software Safety

Systems Engineering—Advanced Certificate for Post-Master’s Study

The challenges in developing products and in solving systems problems are complex and multidisciplinary, requiring engineers who understand and execute programs that require enterprise systems-of-systems engineering discipline. A structured, balanced, comprehensive approach is needed to develop sophisticated architectures, employ innovative enterprise management processes, and deploy global high-technology products, often made up of multiple systems. This graduate program is designed to provide senior engineers and managers who already have a master’s degree in systems engineering with advanced state-of-the-art tools and knowledge that goes beyond the traditional systems engineering program.

The objective of the Advanced Certificate for Post-Master’s Study in Systems Engineering is to provide students with skills and habits of thought employing advanced principles of systems engineering and to contribute to the development of new knowledge through directed research and publication. It is expected that students will participate, possibly in collaboration with their employers, in developing and evolving the body of knowledge in this modern discipline and in improv-
Systems Engineering

Course Descriptions

645.450 Foundations of Human Systems Engineering

Systems are designed, built, and used by humans. Their purpose is to help people meet their goals and perform their tasks. This course introduces the foundations of HSE from which system requirements and design elements are derived. The objective is to provide students with the knowledge of human capabilities and introduce human systems engineering concepts and design principles. Human capabilities include visual, auditory, and touch senses, motion, cognitive processing, and decision making. Human systems engineering concepts and design principles include human factors engineering; training; maintenance; environmental, safety, and health; survivability; habitability; manpower; and personnel.

Prerequisites
645.462 Introduction to Systems Engineering.

Instructors: Beecher, McKneely

645.451 Integrating Humans and Technology

In this course students will learn how to integrate the human into the system and to derive human-based system requirements and design elements. Design preparation will comprise collecting/compiling missions, scenarios, user profiles, and conceptual designs. Human-system analysis processes will introduce work flow; task; social and communications networks; and gap, function, decision, and risk analyses. Topics include: culture and team dynamics; modeling and simulation of human capabilities; human-centered prototyping; human performance measurement; supervision of automation; human considerations in system integration, production, and deployment; and user support.

Prerequisites
645.462 Introduction to Systems Engineering.

Instructors: Beecher, Ockerman

645.462 Introduction to Systems Engineering

This course introduces students to the fundamental principles of systems engineering and their application to the development of complex systems. It describes how the systems engineering viewpoint differs from that of the engineering specialist and the essential role that systems engineering plays as an integral component of program management. Topics include requirements analysis, concept definition, system synthesis, design tradeoffs, risk assessment, interface definition, engineering design, system integration, and related systems engineering activities. The course defines the breadth and depth of the knowledge that the systems engineer must acquire concerning the characteristics of the diverse components that constitute the total system. Special topics such as simulation and models and test and evaluation are discussed in relation to the systems engineering viewpoint. Students address typical systems engineering problems that highlight important issues and methods of technical problem resolution.

Prerequisites
An engineering, science, or mathematics degree and one year of experience in science or engineering, or permission from the student's academic advisor and the course instructor.

Course Requirements—Advanced Certificate for Post-Master's Study

The Advanced Certificate for Post-Master's Study in Systems Engineering is awarded after completion of six courses beyond the MS or MSE in Systems Engineering. It is intended to add depth and breadth in the discipline. The program consists of four required courses and two advanced electives. The student's program will be planned in consultation with an advisor. The two advanced electives can be two semesters of an independent systems engineering research project leading to a paper suitable for submission for publication in a referenced journal or two EP 700-level courses in a program approved by the student's advisor.

Required courses:
645.742 Management of Complex Systems
645.753 Enterprise Systems Engineering
645.761 Systems Architecting
645.771 System of Systems Engineering

Two elective courses:
645.803/804 Post-Master's-Systems Engineering Research Project OR
Two approved 700-level courses in the EP offering.
645.467  Management of Systems Projects

The course addresses the management of a technical project from concept to operational use, with emphasis on the functions, roles, and responsibilities of the project manager. From the development of a proposal to the delivery of a product to a customer, the efforts to conceive, plan, budget, schedule, monitor, control/direct, and report the progress of the project are discussed. Throughout the project life cycle, the need for good communications, interface and configuration management, and conflict resolution is emphasized. Students assume the role of project managers who must use management tools such as WBS, EVM, and CPN and who must address typical problems that arise in the conduct of a high-technology systems project.

Prerequisites
Admission into the Systems Engineering program (not available for Technical Management students).

Instructors: Bernstein, Brown, Cormier, Dever, Hein, Leveque, Jacobus, Neace, Olson, Saunders, Schuck, Utara, Robinson

645.469  Systems Engineering of Deployed Systems

Systems engineering theory typically focuses on the early design and development phases of a system's life cycle, yet over the life of a system, the bulk of engineering effort and the associated costs are not realized until the operations and support (O&S) phase. This course will examine the importance of designing O&S considerations early in a system's life cycle by identifying the appropriate logistic elements and measures, while introducing the necessary analytical processes and tools to support end-to-end life cycle engineering requirements. Manufacturing and production operations will be presented along with the elements that support a system once it is fielded (maintenance planning, reliability prediction, supply support, training, shipping, and system disposal). The course will also explore the requirements and processes associated with major upgrades to deployed systems and the logistics management techniques that must be implemented during initial fielding and deployment. A class project and real-world case studies will underscore the theory and techniques associated with deployed systems engineering.

Prerequisites
645.462 Introduction to Systems Engineering or 645.467 Management of Systems Projects.

Instructors: Finlayson, Herdlick, Metz, Mayoral

645.742  Management of Complex Systems

Traditional systems engineering is usually applied to closed, precise, and recursive systems with the assertion that the methodologies used can be scaled up to more elaborate systems of systems. This course addresses the more realistic and emerging field of the management of complex systems, where multiple current development efforts with disparate and non-linear attributes characterize the system components. Engineering complex systems must account for the likelihood of multiple disciplines, differing scales, often unpredictable future states, irreducible uncertainty, and non-linear behavior. Multi-customer, -corporations, -governments, -technologies, and -systems now must be considered on a global scale with a mix of new and legacy systems. The student will be encouraged to think differently and creatively about the management approaches to developing complex systems and to utilize adaptive strategies and tools including modeling and simulation, pattern recognition, non-linear dynamics, chaos theory, and control systems. Special attention will be given to risk assessment and management for dynamic systems. Case studies and examples will be drawn from commercial industry and DoD systems acquisition programs. Students will be expected to discuss several readings and complete an academic paper to explore in depth one or more of the concepts discussed.

Prerequisites
Selected as one of the electives in the MSE or MS program or a required course in the Advanced Post-Master's Certificate.

Instructor: Crownover

645.753  Enterprise Systems Engineering

Enterprise systems engineering is a multidisciplinary approach combining systems engineering and strategic management to address methods and approaches for aligning system architectures with enterprise business rules and the underlying IT architecture; development and implementation consistent with enterprise strategic objectives; and the total enterprise system and capabilities, with diverse complex subsystems. This course uses the systems engineering life cycle as a framework for linking outcome-based engineering analysis and decision making with enterprise strategic objectives, addressing methods and tools for managing complexity, determining measures of effectiveness and assessing return on investment from an engineering perspective. The complex nature of enterprises will be discussed, including the multiplicity of technical and business components involved in delivering enterprise capability, as well as methods for modeling and analysis of their interdependence. Business and technical interdependencies between infrastructure, computing, applications, services, and end-user environments will be discussed. Particular attention will be paid to outcome-based management, understanding total cost of ownership for delivered capabilities, and end-to-end systems engineering.

Prerequisites
Selected as one of the electives in the MSE or MS program or a required course in the Advanced Post-Master’s Certificate

**Instructors:** Dahmann, Montoya, Ziarko

**Online Option Available**

**645.754 Social and Organizational Factors in Human Systems Engineering**

The objective of this course is to provide students with the knowledge of organizational structure, social interaction, and group behavior needed to reflect the full context of use in the practice of systems engineering. It examines the characteristics of organizations and of social contexts that influence system requirements and design and describes systems engineering processes for discovering, representing, and analyzing such information in practice. It covers the application of these factors throughout the system life cycle. Additional topics include systems in high-reliability organizations, system support for group situation awareness and distributed decision making in command and control systems, and systems engineering for context-aware and social media systems.

**Prerequisites**
645.462 Introduction to Systems Engineering.

**Instructors:** Boa, Gersh

**645.755 Methods in Human-System Performance Measurement and Analysis**

This course focuses on human-system performance measurement (HsPM) methods used to determine whether human-system requirements are met and if the systems’ design provides effective and efficient human-system performance. Students will gain knowledge of HsPM study design protocols, data collection tools and methods, analysis techniques and processes, and procedures required to execute studies with human participants. The course will provide students with an understanding of HsPM in the context of system design; workplace design; environment, safety, and occupational health; training; and maintenance. Students will be exposed to heuristic evaluations; modeling and simulation of human tasking, including tools for measuring physical limitations, cognitive load, and fatigue; and system testing with the human element.

**Prerequisites**
645.462 Introduction to Systems Engineering.

**Instructors:** Beecher, Comperatore

**645.756 Metrics, Modeling, and Simulation for Systems Engineering**

This course takes an integrated, in-depth view of foundational statistical concepts, modeling, and simulation techniques. Knowledge of typical system-level key performance parameters and their stochastic characterization is critical to the systems engineering process as the basis for decision-making from early system conceptualization through retirement. Relevant probability and statistics concepts are covered in the context of SE decision points. Techniques in experimental design, data collection, analysis, and modeling of system metrics as a function of system use and environment are explored as they pertain to characterizing system, subsystem, and component performance. Finally, implementing models in analytic simulations to support requirements, design, upgrade, and replacement/retirement phases of the SE process provides the systems engineer with a solid foundation for making and justifying difficult decisions.

**Prerequisites**

**Instructors:** Dixon, Ryals, Ruben, Vick, West, Youngblood

**645.757 Foundations of Modeling and Simulation in Systems Engineering**

This course provides an introduction to the field of modeling and simulation (M&S) from the perspective of M&S as an essential tool for systems engineering. Topics emphasize the use of M&S to establish and verify key performance parameters, system and subsystem functionality, and interfaces. The course presents an overview of the types of models and simulations used across the phases of the systems engineering life cycle. The strengths and limitations of M&S are explored with respect to the application of M&S use in SE. Examples will be given for several types of systems, including systems developed under the U.S. Department of Defense acquisition process. State-of-the-art M&S tools are introduced, and each student is given the opportunity to construct a model or simulation using a tool of their choice. The Arena modeling tool will be used for some examples. Upon completion of the course, the student will be able to recognize when M&S will provide meaningful support to a technical program, select the appropriate modeling techniques for a given task, lead the development of the model and the modeling of the input data, and analyze the results to support decisions at key milestones of a system's life cycle.

**Prerequisites**
645.462 Introduction to Systems Engineering.

**Instructors:** Coolahan, Jones

**Online Option Available**

**645.758 Advanced Systems Modeling Simulation**

This course is a continuation of Foundations of Modeling and Simulation in Systems Engineering, and provides in-depth exposure to the field of modeling and simulation (M&S) from the perspective of M&S as an essential tool for systems engineering. Advanced statistical methods are used to conduct requirements-driven simulation analysis and experimentation. The course provides treatment of advanced M&S topics, including verification, validation, and accreditation techniques; methods for simulation interoperability and composability; modeling of the system environment, both natural and man-made; modeling of system costs; and the establishment of collaborative M&S environments. The course also explores continuous and real-time simulation. Students are exposed to the techniques used to form conceptual models...
of mechanical (both translational and rotational), electrical, fluid, thermal, biological, and hybrid systems. The conceptual models are transformed into mathematical models and implemented in a modern simulation package. State-of-the-art tools are explored, and each student is given the opportunity to conduct a simulation study of a complex system. Each student will present a case study and complete a project. Upon completion of the course, the student will be able to conduct or lead the development of the model of a complex physical system, model the input data, and analyze the results to support decisions at key milestones of a system's life cycle.

**Prerequisites**
645.757 Foundations of Modeling and Simulation in Systems Engineering and 625.403 Statistical Method and Data Analysis.

**Instructors:** Coolahan, Jones

**Online Option Available**

### 645.761 Systems Architecting

As the systems that systems engineers face become more complex, it is no longer sufficient to use "good engineering practices." The complex systems of today need to be architected before design work can begin. This course examines the principles and art of systems architecting when developing both individual systems and systems that are components of a system or federation of systems. The objective is to provide students with the principles, techniques, and hands-on experience of architecting modern, complex systems. Students will learn the latest architecture development techniques using DoD and commercial architectural frameworks, then extend those frameworks to specific problems involving unique systems development environments. Topics include the management of underlying system and data models and the special architecting requirements of command, control, and communications systems. Special attention will be placed on visualizing architecture artifacts—qualitatively and quantitatively evaluating architectures and the systems model they represent—and utilizing system architectures for investment decisions. Case studies from actual experiences will be presented.

**Prerequisites**
Selected as one of the electives in the MSE or MS program or a required course in the Advanced Post-Master's Certificate.

**Instructors:** Henry, Ryder, Smithson, Topper

**Online Option Available**

### 645.764 Software Systems Engineering

This course for systems engineers covers software engineering principles, artifacts, and approaches for the development of software systems. Topics include software engineering processes and metrics; real-time, distributed, configurable, and object-oriented software; alignment of software systems with overall system design; software-unique aspects of planning, requirements, architecture analysis, design, implementation, testing, and maintenance; understanding important software engineering constraints (performance, security, networking, etc.); and technology trends in software engineering today. Student teams will conduct case studies for a project.

**Prerequisites**
645.462 Introduction to Systems Engineering, or permission from the student's academic advisor and the course instructor.

**Course Notes**

Note: Students may not enroll in this course if they have already completed 595.763 Software Engineering Management. This course is not available to Technical Management students.

**Instructors:** Britcher, Herder, Kovalchik, Paafford, Saunders, Secen, Tamer, Thompson, Valencia

**Online Option Available**

### 645.767 System Conceptual Design

This course addresses in detail the systems engineer's responsibilities and activities during the conceptual phases of a system development program. Systems engineering tools commonly employed at this stage of a program are presented along with selected problems that illustrate both the applicability and limitations of commonly employed tools and procedures. The course steps through conceptual design beginning with analysis of needs and objectives and proceeding to the exploration of alternative concepts and the selection of a concept that best meets goals of performance, timeliness, and affordability. Topics include definition of operational scenarios, functional analysis, risk assessment, system tradeoffs, measures of effectiveness, and requirements formulation. Emphasis is on the application of these systems engineering techniques in a team environment to a class project. Students apply systems engineering methods learned from reading and lectures to the development of a realistic system in an ongoing project in a team format.

**Prerequisites**
645.462 Introduction to Systems Engineering and 645.467 Management of Systems Projects, or permission of the student's advisor and the course instructor.

**Instructors:** Biemer, Britcher, Dixon, Flanigan, Keller, Levin, Moreno, Paulhamus, Russell, Ryder, Saxon, Secen, Smith, Smyth, Starr, Topper, Utara

**Online Option Available**

### 645.768 System Design and Integration

This course addresses the systems engineering objectives, responsibilities, and activities during the demonstration and validation and the engineering and manufacturing development phases of a system development program. Systems engineering procedures and tools employed during these phases are identified and their use illustrated. Topics include the relationship between a system specification and the system design, systems engineering management plans, risk management, system development models, customer integration into the design process, and design disciplines and practices. The course uses a system problem scenario extensively to illustrate
systems engineering principles and specific product design issues.

**Prerequisites**
645.767 System Conceptual Design or permission of the student’s advisor and the instructor.

**Instructors:** Ahlbrand, Barton, Biemer, Britcher, Campbell, Fidler, Harmattuk, Haer, Martinell, Saunders, Saxon, Secon, Smith, Utara, Warren, White

645.769 **System Test and Evaluation**
This course focuses on the application of systems engineering principles to the test and evaluation of system elements and, ultimately, of the total system. Test requirements, selection of critical test parameters, analysis of test results, and determination of remedial action in the event of discrepancies are all systems engineering functions. Topics include validation and verification, similarities and differences in the nature of hardware and software testing, test tools and test procedures, testing during hardware-software integration, quality assurance test, environmental test, and operational test and evaluation. Student problems include scenario case studies using examples developed in the several previous courses.

**Prerequisites**
645.768 System Design and Integration or permission of the student's advisor and the instructor.

**Instructors:** Fidler, Finlayson, Harmattuk, Kim, Kryzstan, Neace, O'Connor, Ryba, Selby, Sprigg, Tarchalski, Thompson, Ziarko

645.771 **System of Systems Engineering**
This course addresses the special engineering problems associated with conceiving, developing, and operating systems composed of groups of complex systems closely linked to function as integral entities. The course will start with the underlying fundamentals of systems' requirements, design, test and evaluation, and deployment, and how they are altered in the multi-system environment. These topics will then be extended to information flow and system interoperability, federated modeling and simulation, use of commercial off-the-shelf elements, and systems engineering collaboration between different organizations. Advanced principles of information fusion, causality theory with Bayesian networks, and capability dependencies will be explored. Several case studies will be discussed for specific military systems of systems, including missile defense and combatant vehicle design, as well as selected commercial examples.

**Prerequisites**
Selected as one of the electives in the MSE or MS program or a required course in the Advanced Post-Master's Certificate.

**Instructors:** Biemer, Ciotti, Fidler, Jones, Montoya

645.800 **Systems Engineering Master's Project**
This course provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific practical project that is suggested by the student and is presented in a formal proposal. The product of the system project is a final report, as well as interim reports and an oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the systems engineering faculty. The program chair, vice chair, and mentor review proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses (formerly 645.770).

**Prerequisites**
645.769 System Test and Evaluation or permission of the program chair or vice chair.

**Instructors:** Seymour, Utara, Thompson

645.801/802 **Systems Engineering Master's Thesis**
This course is designed for students in the systems engineering master's program, who will work with an advisor to conduct independent research in the field of systems engineering leading to a paper that is publishable in a refereed journal. It is also desirable the paper be presented in a professional meeting. The intent of the research is to advance the body of knowledge and the understanding of systems engineering practices, the improvement of systems engineering practices in industry and in government, the evolution of systems engineering tools and techniques, and the solution of systems development issues in the acquisition of advanced systems. Students intending to pursue a doctoral degree should enroll in this course.

**Prerequisites**
Completion of all other courses applicable to the systems engineering master's degree.

**Course Notes**
Students who plan to register for this course will need to contact the Systems Engineering Program Office (443-778-6002) four to six weeks prior to the semester start date.

**Instructor:** Strawser

645.803/804 **Post Master's-Systems Engineering Research Project**
This course is designed for students in the systems engineering post master's advanced certificate program, who will work with an advisor to conduct independent research in the field of systems engineering leading to a paper that is publishable in a refereed journal. It is also desirable the paper be presented in a professional meeting. The intent of the research is to advance the body of knowledge and the understanding of systems engineering practices, the improvement of systems engineering practices in industry and in government, the evolution of systems engineering tools and techniques, and the solution
of systems development issues in the acquisition of advanced systems.

**Prerequisites**
MSE or MS in Systems Engineering and three of the four required advanced post master’s systems engineering courses.

**Course Notes**
Students who plan to register for this course will need to contact the Systems Engineering Program Office (443-778-6002) four to six weeks prior to the semester start date.

**Instructor:** Strawser

645.805 **Biomedical Systems Engineering Master’s Project**
This course is intended for students in the biomedical systems engineering concentration and provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific biomedical systems project that is suggested by the student and is presented in a formal proposal. The product of the biomedical system project is a final report, as well as interim reports and an oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the biomedical or systems engineering faculty. The biomedical program chair, the systems engineering vice chair, a systems engineering mentor, and a biomedical mentor review student proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses.

**Prerequisite**
Completion of all courses applicable to the biomedical systems engineering master's degree.

**Instructor:** Staff

645.806 **Cybersecurity Systems Engineering Master's Project**
This course is intended for students in the Cybersecurity Systems Engineering concentration and provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific cyber security system project that is suggested by the student and is presented in a formal proposal. The product of the cyber security system project is a final report, as well as interim reports and an oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the computer science or systems engineering faculty. The computer science program chair, the systems engineering vice chair, a systems engineering mentor, and a computer science mentor review student proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses.

**Prerequisites**
Completion of all other courses applicable to the Cybersecurity Systems Engineering master's degree.

**Instructor:** Staff

645.807 **Software Systems Engineering Master’s Project**
This course is intended for students in the software systems engineering focus area and provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific software systems project that is suggested by the student and is presented in a formal proposal. The product of the software systems project is a final report, as well as interim reports and an oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the computer science or systems engineering faculty. The computer science program representative, the systems engineering vice chair, a systems engineering mentor, and a computer science mentor review student proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses.

**Prerequisite**
Completion of all other courses applicable to the software systems engineering master's degree.

**Instructor:** Staff

645.808 **Human Systems Engineering Master’s Project**
This course is intended for students in the human systems engineering concentration and provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific human systems project that is suggested by the student and is presented in a formal proposal. The product of the human systems project is a final report, as well as interim reports and an oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the systems engineering or human systems concentration faculty. The systems engineering chair, a systems engineering mentor, and a human systems concentration mentor review student proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses.

**Prerequisites**
Completion of all other courses applicable to the human systems engineering master's degree.

**Instructor:** Staff
Technical Management

Supervisory and management positions in scientific and engineering organizations are usually awarded to staff members who have earned the respect of management and coworkers by excelling in their areas of technical expertise. They then act as “lead scientists” or “lead engineers,” directing the work of other scientists or engineers. Although they have proved that they have good judgment in strictly technical matters, there may be nothing in their past education or work experience that has prepared them for supervisory and management responsibilities.

The overall objective of the Technical Management program is to prepare individuals trained and experienced in science or engineering in the elements of leading technical projects and organizing and supervising technical personnel. The program is organized along five focus areas: Project Management—the organization and direction of specific technical projects; Organization Management—the organization and leading of people to accomplish technical objectives; and Project/Organization Management—a combination of the previous two. A focus in Technical Innovation Management addresses the personal and organizational management of innovation and the development of new technical ventures. The newly offered focus area in Quality Management will focus on preparing technical leaders to manage programs to high-quality standards like ISO9001, AS9100, and CMMI. The focus area will offer an introductory course as well as advanced courses focusing on the quality aspects of technical programs and software engineering.

Instructional methodology employs a mixture of lectures on theory and practice by experienced technical senior leaders and executives and realistic problem situations in which students play a management role, dealing with problems and making decisions that are typically required of technical managers. Management theories and tools are presented in the context of problem situations.

Appropriate emphasis is given to that blend of technical, administrative, business, and interpersonal skills required for the successful management of continuously changing high-technology organizations and projects.

Students are encouraged to pursue the entire master’s degree but in special approved cases may apply for the Graduate Certificate in Technical Management. The requirements for admission are the same as for the master’s degree, and the student must complete six courses, as approved by the program chair/vice chair, with a grade of B– or higher [see Admission Requirements (page 4)].

New Developments in Technical Management

The Technical Management program is currently developing two new high-level courses offering advanced topics in project planning and control and executive technical leadership. These career-focused courses will be offered to Technical Management students in late 2013 and early 2014, respectively.

Program Committee

Joseph J. Suter, Chair
Principal Professional Staff
Applied Physics Laboratory

James T. (Ted) Mueller, Vice Chair
Principal Professional Staff
Applied Physics Laboratory

William W. Agresti
Associate Dean for Professional Programs
Carey Business School

Richard W. Blank
Principal Professional Staff
Applied Physics Laboratory

Alon D. Harris, III
General Engineer, Office of Disposal Operations,
Environmental Management
U.S. Department of Energy

Stephen A. Shinn
Deputy Director, Flight Projects
NASA Goddard Space Flight Center

Admission Requirements

Applicants must meet the general requirements for admission to a graduate program outlined in this catalog [see Admission Requirements (page 4)]. In addition, the applicant must have a degree in a science or engineering field and must have a minimum of two years of relevant full-time work experience in that field. A detailed resume must be submitted with the application form.

Course Requirements

All students complete 10 one-term courses, at least three of which must be 700-level courses, within five years. Students may elect to pursue one of five focus areas:

• Project Management
• Organization Management
• Project/Organization Management
• Technical Innovation Management
• Quality Management

Neither a thesis nor knowledge of a foreign language is required in this program. Academic standards governing graduate study, as specified in this catalog, must be maintained.

Technical Management—Online

There are numerous courses in the Technical Management program offered in a fully online format, and more courses are continually being developed. This increases the flexibility of course offerings for students wishing to pursue studies in either the on-site or online format, or a combination of both.
Online course content is identical to that of the on-site offerings but available in a structured, class-paced (not self-paced), asynchronous mode over the Internet. Students should start accessing and working on their online classes on the first day of the semester to avoid falling behind. Recorded lectures with associated multimedia content are augmented with online discussions and weekly synchronous office hours. Teams are often used for assignments, and early engagement with designated team members is advised. Prospective and current students should consult the EP website for the most current online course offerings, course schedules, and procedures for online programs.

**Course Descriptions**

Technical Management courses are primarily for those students who have been accepted as candidates for the master's degree. Degree candidates are given preference in registering. Special Students, including students from other degree programs, may be admitted on a space-available basis, provided they meet the same admission criteria as Technical Management degree candidates.

Prior or concurrent completion of 595.460 Introduction to Project Management and 595.461 Technical Group Management (taken in either order) is generally prerequisite to more advanced courses. Specific prerequisites for each course are shown under the individual course descriptions. An approved program plan is required for preferential placement in registering.

Courses numbered 600 and above are open only to students who have been admitted to graduate status.

Note: 595.802 Directed Studies in Technical Management is offered across all focus areas.

Courses are offered at the Applied Physics Laboratory (APL) Education Center, the Montgomery County Campus, the Dorsey Center, and the Southern Maryland Higher Education Center in St. Mary’s County. Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

### I. Required Courses for Project Management (7 Courses)

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<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tr>
<td>595.460</td>
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<td>595.461</td>
<td>Technical Group Management</td>
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<td>595.464</td>
<td>Project Planning and Control I</td>
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<td>595.465</td>
<td>Communications in Technical Organizations</td>
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<tr>
<td>595.466</td>
<td>Financial and Contract Management</td>
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<td>595.763</td>
<td>Software Engineering Management</td>
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<td>645.462</td>
<td>Introduction to Systems Engineering</td>
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Plus three electives from the EP and Carey School electives lists.

### II. Required Courses for Organization Management (7 Courses)

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<td>595.466</td>
<td>Financial and Contract Management</td>
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<tr>
<td>595.762</td>
<td>Management of Technical Organizations</td>
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Plus three electives from the EP and Carey School electives lists.

### III. Required Courses for Project/Organization Management (9 Courses)

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<td>Management of Technical Organizations</td>
</tr>
<tr>
<td>595.763</td>
<td>Software Engineering Management</td>
</tr>
<tr>
<td>645.462</td>
<td>Introduction to Systems Engineering</td>
</tr>
</tbody>
</table>

Plus one elective from the EP and Carey School electives lists.

### IV. Required Courses for Technical Innovation Management (8 Courses)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>595.460</td>
<td>Introduction to Project Management</td>
</tr>
<tr>
<td>595.461</td>
<td>Technical Group Management</td>
</tr>
<tr>
<td>595.465</td>
<td>Communications in Technical Organizations</td>
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<tr>
<td>595.466</td>
<td>Financial and Contract Management</td>
</tr>
<tr>
<td>595.468</td>
<td>Fundamentals of Technical Innovation in Organizations</td>
</tr>
<tr>
<td>592.762</td>
<td>Management of Technical Organizations</td>
</tr>
<tr>
<td>595.766</td>
<td>Advanced Technology</td>
</tr>
<tr>
<td>635.792</td>
<td>Management of Innovation</td>
</tr>
</tbody>
</table>

Plus two electives from the Carey School electives list.

### V. Required Courses for Quality Management (7 Courses)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>595.460</td>
<td>Introduction to Project Management</td>
</tr>
<tr>
<td>595.464</td>
<td>Project Planning and Control I</td>
</tr>
<tr>
<td>595.740</td>
<td>Assuring Success of Aerospace Programs</td>
</tr>
<tr>
<td>595.741</td>
<td>Engineering Quality Management</td>
</tr>
<tr>
<td>595.760</td>
<td>Introduction to Quality Management</td>
</tr>
<tr>
<td>595.763</td>
<td>Software Engineering Management</td>
</tr>
<tr>
<td>645.462</td>
<td>Introduction to Systems Engineering</td>
</tr>
</tbody>
</table>

Plus three electives from the list below or the Carey School electives list.

<table>
<thead>
<tr>
<th>Course Code</th>
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<tbody>
<tr>
<td>595.461</td>
<td>Technical Group Management</td>
</tr>
<tr>
<td>595.463</td>
<td>Technical Personnel Management</td>
</tr>
</tbody>
</table>
595.460 Introduction to Project Management
This course concentrates on the general methodology of managing a technical project from concept to operational use, with emphasis on the functions, roles, and responsibilities of the project manager. Topics include career aspects of project management; business factors affecting the project and the manager; project organization, planning, execution, and communications; the project life cycle; risk analysis; interface management; design review; design control assessment; reporting; and reaction to critical problems. Students are formed into groups, are presented with a scenario that simulates the development of a high technology system, and are assigned to make decisions required of the project manager in the execution of the project. The project manager's decisions must then be effectively communicated (and perhaps defended) to a variety of audiences (represented by other students and faculty) that include top management, the customer, functional management, and members of the project team.

Prerequisites
An engineering, science, or mathematics degree and two years’ work experience in science or engineering.

Instructors: Blank, Buchanan, Dabbah, Holub, Kedia, Powers, Simpson, Supplee, Tarchalski, Tuck

Online Option Available

595.461 Technical Group Management
This course covers the general functions and responsibilities of a technical group supervisor. Topics include functions of a technical group in an R&D or engineering organization; primary responsibilities of a group supervisor; interactions with management, support organization, and project organization; organization of projects in group structure; development of work costs and schedules; progress monitoring and reporting; introduction to personnel management—leadership, motivation, evaluation, and professional growth; reaction to critical problems; technical leadership; and planning for the future. Students assume the roles of technical group supervisors in a high-technology organization. They address typical problems in delegating responsibilities, staffing new projects, dealing with project managers, and handling conflicts and priorities.

Prerequisites
595.460 Introduction to Project Management or the permission of the student's advisor or the course instructor. In addition, an engineering, science, or mathematics degree and two years' work experience in science or engineering or permission of the program chair/vice chair.

Instructors: Battista, Bigelow, Bjerkaas, Cormier, Fletcher, Fox-McIntyre, Harris, Hendricks, Hestnes, Horne-Jahrling, Regan, Taylor, Tuck

Online Option Available

595.463 Technical Personnel Management
This course reviews the problems of personnel management in a technical organization. Topics include environmental requirements for effective and innovative technical efforts, direction and motivation, leadership behavior, recruitment of technical staff, orientation and training programs, personnel placement and reassignment, assignment of work, salary administration, personnel evaluation and counseling, professional growth and promotion, technical obsolescence and...
retraining, equal opportunity programs, employee grievances, and handling of conflict situations. Students explore typical personnel management situations that arise in a technical organization.

**Prerequisites**
595.461 Technical Group Management or permission of the student's advisor or the course instructor.

**Instructors:** Cormier, Hendricks, Jackson, Lasky, Taylor, Williams

Online Option Available Summer 2013

### 595.464 Project Planning and Control I

This course concentrates on the exploration of the planning and control decisions required when developing a new high-technology product. Students are formed into groups and presented with a scenario that requires the development of a plan that will guide their organization through entry into a new business area. When developing the new product-offering plan, students must consider a wide variety of questions that their top management will need to have answered prior to making a decision to either accept or reject the plan. Other topics include the role of planning and control in project management; processes for responding to a request for proposal (RFP); assignments to prepare a statement of work (SOW), a work breakdown structure (WBS), and a critical path network (CPN) for the new product development plan; earned value performance measurement; analysis of project performance measures; integrated project planning; new product development considerations; enterprise information systems applications; and risk management.

**Prerequisites**
595.460 Introduction to Project Management or the permission of the student's advisor or the course instructor.

**Instructors:** Broadus, Cormier, Devereux, Egli, Liggett, McLaughlin, Pardoe, Shinn, Supplee, Suter, Taylor, Utara

Online Option Available

### 595.465 Communications in Technical Organizations

This course covers problems and instruction in human communications within a technical organization. Topics include the nature of difficulties in human communications (perception and cognition, semantics, individual differences in processing information, and listening), techniques for effective oral and written communications and presentations, problems in communication between supervisors and subordinates, assignment of work, and reporting to management and sponsors. Students assume roles in various interpersonal situations, meetings, discussions, and conflicts calling for a supervisor to write letters and memoranda; they also deliver oral presentations and participate in group and one-on-one discussions.

**Prerequisites**
595.460 Introduction to Project Management or 595.461 Technical Group Management, completed or taken concurrently.

**Instructors:** Bjerkaas, Fletcher, Horne-Jahrling, Izenberg, LaBatt, Supplee, Tuck

Online Option Available

### 595.466 Financial and Contract Management

This course is an introduction to financial and contract management for technical managers. Topics include financial and management accounting (including elementary accounting principles, assets, liabilities, and stockholders’ equity); direct and indirect costs, revenues, and profits; indices to financial position; use of financial reports; return on investment, net present value; internal rate of return; and financial management (including cash and funds flow statements). An introduction to the principles of contract formation is presented—highlighting the distinctive characteristics of contracting with the federal government—as well as the team concept for effective contracting and the role of the program manager as a key team member. Subcontract management, competitive negotiation techniques, contract financing, and cost reimbursement are also included. Case studies supplement theoretical discussions.

**Prerequisites**
595.460 Introduction to Project Management or 595.461 Technical Group Management, completed or taken concurrently.

**Instructors:** Langhauser, Warner, Wyant

Online Option Available

### 595.468 Fundamentals of Technical Innovation in Organizations

This course is designed to take graduate students majoring primarily in technical disciplines through the fundamental aspects of managing technical innovations in organizations. It will draw on interdisciplinary concepts from the technical and managerial fields of study, and will specifically focus on how technical innovation management drives the long-term competitiveness of organizations operating in the global socio-economic environment. One of the major objectives of this course is to help students understand various fundamental frameworks for managing technical resources, technical capabilities and technical competencies for growth and renewal of their enterprises. Students will learn the basics of knowledge management, intellectual property rights, and the product-process life cycle vis-à-vis international trade patterns.

**Instructors:** Sharif, Swann

### 595.740 Assuring Success of Aerospace Programs

Technical managers, systems engineers, lead engineers, and mission assurance professionals will benefit from this course, which focuses on the leadership of system safety and mission assurance activities throughout the life cycle of a project
to achieve mission success. This advanced course provides crucial lessons learned and proven best practices that technical managers need to know to be successful. The integrated application of mission assurance and system engineering principles and techniques is presented in the context of aerospace programs, and is also applicable to other advanced technology research and development programs. Students discuss critical risk-based decision making required from system concept definition and program planning through design, procurement, manufacturing, integration and test, launch, and mission operations. Shared experiences by senior aerospace leaders and extensive case studies of actual mishaps explore quality management topics relevant to aircraft, missiles, launch vehicles, satellites, and space vehicles. The course addresses contemporary leadership themes, government policies, and aerospace industry trends in mission assurance requirements, organizational structure, knowledge sharing and communication, independent review, audit, and assessment. Mission assurance disciplines covered include risk management, system safety, reliability engineering, software assurance, supply chain management, parts and materials, configuration management, requirements verification and validation, nonconformance, and anomaly tracking and trending.

**Instructors:** Day, Dever

Online Option Available

**595.741 Engineering Quality Management**

This course addresses quality assurance topics that are suitable in applications for various engineering disciplines. Course discussions include the latest in quality and business management, strategic planning, productivity improvement tools, techniques, and the implementation of quality initiatives. Advanced topics related to the principles and application of total quality methodologies are presented. Students discuss implementing quality assurance tools and systems, including benchmarking, process control, quality measurement, concurrent engineering, Taguchi methods, supplier quality management (SQM), and auditing. Current applications and strategies are introduced such as lean manufacturing philosophy, Deming’s PDSA cycle, Kaizen continuous improvement process, strategic planning, total employee participation, business process re-engineering, and the views of various quality “gurus.” The course covers the Malcolm Baldrige Award criteria, and a comprehensive practical understanding of the ISO 9001 and AS9100 standards are discussed.

**Instructors:** Mueller, Seifert

**595.760 Introduction to Quality Management**

Quality management is developed as an integrated system of management for organizational improvement. Topics covered include the quality management guiding principles of leadership commitment, customer focus, employee involvement/teammwork, continuous process improvement, and the systematic use of measurement data. Case studies of technical organizations and government agency experiences describe adapting quality management in diverse organizations to improve the performance of products and services in satisfying customer needs. Students draw upon theory and practice, recent journal articles, multimedia presentations, and their own work experiences in tailoring applications of the material to their workplace. Guest speakers discuss real-world examples of the various aspects of quality management. Students participate in highly interactive classroom discussions based upon these materials and assignments.

**Instructors:** Cormier, Rahl

**595.762 Management of Technical Organizations**

This course reviews challenges in the management of high-technology organizations at the senior technical management level. Topics include management of change and managing managers; establishing organization, technical, and business objectives and strategies; market analysis, technology, and product development; planning and costing; staffing and training to meet new needs; managing independent research and development; organizational conflicts; technical, financial, and personnel problems; and interaction with top management, staff executives, peers, and subordinates. Students assume the roles of senior technical managers dealing with typical problems in a department, including applied research, product development, and engineering support in an environment of rapidly changing technology.

**Prerequisites**

595.460 Introduction to Project Management, 595.463 Technical Personnel Management, 595.464 Project Planning and Control I, 595.465 Communication in Technical Organizations, 595.466 Financial and Contract Management, or permission of the student’s advisor and the course instructor.

**Instructors:** Harris, Mueller, Suter

Online Option Available

**595.763 Software Engineering Management**

This course covers the activities, methods, and processes needed to manage software engineering and software development projects using current best practices. Course material highlights the differences and the similarities in managing software versus hardware projects. Topics include definition and description of project framework activities and umbrella activities; estimating technical resources, project schedules, and cost; fundamentals in tracking the project using earned value measurement; approaches to building quality, maintainability, security, and other desirable characteristics into the system from the beginning; communicating with teams and customers; and CMMI and ISO. Students will develop a management plan for a project.

**Prerequisites**

645.462 Introduction to Systems Engineering or permission of the student’s advisor or the course instructor. Completion of 595.460 Introduction to Project Management is helpful. Students may not take this course if they have taken 645.764
Software Systems Engineering. This course is not available to Systems Engineering students.

**Instructors:** Battista, Caruso, Cormier, Hopkins, Johnson, Mosley, Shaner, Swain, Thomas

Online Option Available Fall 2013

595.764 **Project Planning and Control II**

This course is intended for anyone who desires to explore project planning and control in more detail and how to improve these processes through the use of earned value, cost and schedule integration, and cost estimating. Specific topics will focus on schedule management, network logic, establishing a traceable schedule, risk assessment, the estimating process and types, earned value and measuring accomplishment, industry trends and tools, integrated baseline reviews, variance analysis, compliance, maintenance, and surveillance, handling subcontracts and procurements, and implementation of the project management process. The intended audience includes project and program managers, project technical personnel, procurement activity personnel, and the stakeholders and owners of projects. While it is intended for a wide range of students, each is assumed to have a basic familiarity with the requirements and the disciplines of project management.

**Prerequisites:**
595.464 Project Planning and Control I

**Instructors:** Battista, Hunter, Liggett, Shinn

**When Offered:** Fall 2013

Online Option Available Spring 2014

595.766 **Advanced Technology**

This course emphasizes the impact of recent technological advances on new products, processes, and needs, as well as the role of the technical manager in rapidly evolving technologies. Subject areas and lecture content track current topics of interest, such as trends and developments in microelectronics, communications, computers, intelligent machines, and expert systems. Advanced technologies in application areas such as transportation, space, manufacturing, and biomedicine are also discussed. Students are encouraged to explore new technology areas and share information with each other. The seminar format encourages student participation that culminates in a term paper on a new or emerging technology area.

**Prerequisites**
595.460 Introduction to Project Management or 645.462 Introduction to Systems Engineering, and 595.468 Fundamentals of Technical Organizations; or permission of the student’s advisor and the course instructor.

**Instructors:** Seifert, Strawser, Suter

595.781 **Executive Technical Leadership**

This course is intended to give a view into various technical executive roles to help the student understand the responsibilities of technical executive leaders. It will help the student decide if technical executive management is a career of interest and to position the student for further study at the Carey Business School. The course sets a context through a framework which introduces the typical roles and responsibilities across the life cycle of a technical executive position. Examples of technical executive positions are VP/Director of R&D or Engineering, Technical Director (Government), Program Management Executive, Chief Engineer, Chief Technical Officer (CTO), and Chief Information Officer (CIO). The course also addresses the culture of organizations and emphasizes the “soft skills” needed to lead and transform a technical organization. Leadership topics such as mentoring, succession planning, and organizational development are also introduced. The course is designed to introduce topics relevant to technical executives via a life-cycle framework and then to fortify the concepts with guest speakers who are practicing or retired technical executives. The guest speakers will deliver practical career experiences to reinforce the topics presented in the topical framework.

The format of this course is very different from other Technical Management courses. Some lectures (9) will be offered online, and the student is required to attend two weekend sessions at the Homewood campus. The meetings at Homewood will consist of team assignments and seminars by senior leaders.

**Prerequisites**
595.762 Management of Technical Organizations, an interview with the instructors, and an exemplary academic record.

**Instructors:** Blank, Suter, Tarchalski

**When Offered:** Spring 2014

595.802 **Directed Studies in Technical Management**

In this course, qualified students are permitted to investigate possible research fields or to pursue problems of interest through reading or nonlaboratory study under the direction of faculty members.

**Prerequisites**
The Directed Studies Program Proposal Form (available from the student’s advisor) must be completed and approved prior to registration.

**Course Note**
This course is open only to candidates in the Master of Science in Technical Management program.

**Instructors:** Happel, Suter
Policy Statements

Equal Opportunity/Nondiscriminatory Policy as to Students
The Johns Hopkins University is committed to recruiting, supporting, and fostering a diverse community of outstanding faculty, staff, and students. As such, Johns Hopkins does not discriminate on the basis of gender, marital status, pregnancy, race, color, ethnicity, national origin, age, disability, religion, sexual orientation, gender identity or expression, veteran status, or other legally protected characteristic in any student program or activity administered by the university or with regard to admission or employment. Defense Department discrimination in Reserve Officer Training Corps (ROTC) programs on the basis of sexual orientation conflicts with this university policy. The university continues its ROTC program, but encourages a change in the Defense Department Policy.

Questions regarding Title VI, Title IX, and Section 504 should be referred to the Office of Institutional Equity, 410-516-8075 or (TTY) 410-516-6225.

Policy on the Reserve Officer Training Corps
The Johns Hopkins University admits students of any race, color, gender, religion, age, national or ethnic origin, disability, marital status, or veteran status to all of the rights, privileges, programs, benefits, and activities generally accorded or made available to students at the university. It does not discriminate on the basis of race, color, gender, marital status, pregnancy, ethnicity, national origin, age, disability, religion, sexual orientation, gender identity or expression, veteran status, or other legally protected characteristic in any student program or activity administered by the university, including the administration of its educational policies, admission policies, scholarship and loan programs, and athletic and other university-administered programs or in employment.

Questions regarding Title VI, Title IX, and Section 504 should be referred to the Office of Institutional Equity, Garland Hall 130, 410-516-8075, (TTY) 410-516-6225.

Admissions Policy
Johns Hopkins University admits as regular students only persons who have a high school diploma or its recognized equivalent, or persons who are beyond the age of compulsory school attendance in Maryland.

To be eligible for federal student aid, students who are beyond the age of compulsory attendance but who do not have a high school diploma or its recognized equivalent must meet ability-to-benefit criteria or meet the student eligibility requirements for a student who is home schooled.

Statement Regarding the Privacy Rights of Students
Notice is hereby given that the Johns Hopkins Engineering for Professionals program complies with the provisions of the Family Educational Rights and Privacy Act (FERPA) of 1974 (P.L. 93-380), as amended, and regulations promulgated thereunder. FERPA affords eligible students with certain rights with respect to their education records. These rights are as follows: (1) The right to inspect and review the student’s education records within 45 days of the day the university receives a request for access. Students should submit to the Registrar written requests that identify the record(s) they wish to inspect. The Registrar will make arrangements for access and notify the student of the time and place where the records may be inspected. If the records are not maintained by the Registrar, the student will be advised of the correct official to whom the request should be addressed. (2) The right to request amendment of education records that the student believes are inaccurate or misleading. Students should write to the university official responsible for the record they want changed and specify why it is inaccurate or misleading. If the university decides not to amend the records as requested by the student, the student will be notified of the decision and advised of his or her right to a hearing regarding the request for amendment. Additional information regarding the hearing procedures will be provided to the student when notified of the right to a hearing. (3) The right to consent to disclosures of personally identifiable information contained in the student’s education records, except to the extent that FERPA authorizes disclosures without consent. Disclosure without consent is granted to school officials with legitimate educational interests. A school official is a person employed by the university in an administrative, supervisory, academic or research, or support staff position (including law enforcement unit personnel and health staff); a person serving on the board of trustees; or a student serving on an official committee, such as a disciplinary or grievance committee, or assisting another school official in performing his or her tasks. A school official has a legitimate educational interest if the official needs to review an education record in order to fulfill his or her professional responsibility. (4) The right to file a complaint with the U.S. Department of Education concerning alleged failures by the university to comply with the requirements of FERPA.

The name and address of the office that administers FERPA is:
Family Policy Compliance Office
U.S. Department of Education
400 Maryland Avenue S.W.
Washington, DC 20202-4605

Americans with Disabilities Act Policy (ADA)
The Johns Hopkins University does not discriminate on the basis of gender, marital status, pregnancy, race, color, ethnicity, national origin, age, disability, religion, sexual orientation, veteran status or other legally protected characteristic in any student program or activity administered by the university or with regard to admission or employment.

A person with a disability is defined by the Rehabilitation Act of 1973 and by the Americans with Disabilities Act of 1990 as an individual who has a physical or mental
impairment that substantially limits one or more major life activities, has a record of such an impairment, or is regarded as having such an impairment. For persons with disabilities it is important to provide to the university a comprehensive evaluation of a specific disability from an appropriate qualified diagnostician that identifies the type of disability, describes the current level of functioning in an academic or employment setting and lists recommended accommodations. The university provides appropriate, necessary, and reasonable accommodations in programs and facilities for those individuals who are qualified.

The policy is available on the JHU Office of Institutional Equity (OIE) website at web.jhu.edu/administration/jhuie/disability.html. Questions regarding compliance with the provisions of the Americans with Disabilities Act of 1990 and Section 504 of the Rehabilitation Act of 1973 should be referred to Disability Services, Office of Institutional Equity, 410-516-8949 or (TTY) 410-516-5300.

Sexual Harassment Prevention and Resolution Policy

Preamble

The Johns Hopkins University is committed to providing its staff, faculty, and students the opportunity to pursue excellence in their academic and professional endeavors. This can exist only when each member of our community is assured an atmosphere of mutual respect, one in which they are judged solely on criteria related to academic or job performance. The university is committed to providing such an environment, free from all forms of harassment and discrimination. Each member of the community is responsible for fostering mutual respect, for being familiar with this policy, and for refraining from conduct that violates this policy.

Sexual harassment, whether between people of different sexes or the same sex, is defined to include, but is not limited to, unwelcome sexual advances, requests for sexual favors, and other behavior of a sexual nature when:

1. Submission to such conduct is made implicitly or explicitly a term or condition of an individual’s employment or participation in an educational program
2. Submission to or rejection of such conduct by an individual is used as the basis for personnel decisions or for academic evaluation or advancement
3. Such conduct has the purpose or effect of unreasonably interfering with an individual’s work or academic performance or creates an intimidating, hostile, or offensive working or educational environment

Fundamental to the university’s purpose is the free and open exchange of ideas. It is not, therefore, the university’s purpose, in promulgating this policy, to inhibit free speech or the free communication of ideas by members of the academic community.

Policy

The university will not tolerate sexual harassment, a form of discrimination, a violation of federal and state law, and a serious violation of university policy. In accordance with its educational mission, the university works to educate its community regarding sexual harassment. The university encourages individuals to report incidents of sexual harassment and provides a network of confidential consultants by which individuals can report complaints of sexual harassment. The means by which complaints are resolved can range from informal to formal.

The university encourages reporting of all perceived incidents of sexual harassment, regardless of who the alleged offender may be. Individuals who either believe they have become the victim of sexual harassment or have witnessed sexual harassment should discuss their concerns with any member of the Sexual Harassment Prevention and Resolution system. Complainants are assured that problems of this nature will be treated in a confidential manner, subject to the university’s legal obligation to respond appropriately to any and all allegations of sexual harassment.

The university prohibits acts of reprisal against anyone involved in lodging a complaint of sexual harassment. Conversely, the university considers filing intentionally false reports of sexual harassment a violation of this policy.

The university will promptly respond to all complaints of sexual harassment. When necessary, the university will institute disciplinary proceedings against the offending individual, which may result in a range of sanctions, up to and including termination of university affiliation.

Complaints of sexual harassment may be brought to Susan Boswell, Dean of Student Life, 410-516-8208; Ray Gillian, Vice Provost for Institutional Equity; or Caroline Laguerre-Brown, Director of Equity Compliance and Education, 410-516-8075 or (TTY) 410-516-6225.

University Alcohol and Drug Policy for Students

In keeping with its basic mission, the university recognizes that its primary response to issues of alcohol and drug abuse must be through educational programs, as well as through intervention and treatment efforts. To that end, the university provides appropriate programs and efforts throughout the year. The brochure “Maintaining a Drug-Free Environment: The Hopkins Commitment” is distributed annually to all faculty, students, and staff of the Johns Hopkins University, and copies are available on request from the offices of the Faculty and Staff Assistance Program, 4 East 33rd Street, Baltimore, Maryland 21218, 410-516-3800; or at the Counseling and Student Development Center located on the Homewood Campus, 410-516-8270.

Policy on Possession of Firearms on University Premises

Possessing, wearing, carrying, transporting, or using a firearm or pellet weapon is strictly forbidden on university premises. This prohibition also extends to any person who may have acquired a government-issued permit or license. Violation
of this regulation will result in disciplinary action and sanctions up to and including expulsion in the case of students, or termination of employment in the case of employees. Disciplinary action for violations of this regulation will be the responsibility of the divisional student affairs officer, dean or director, or the vice president for human resources, as may be appropriate, in accordance with applicable procedures. Any questions regarding this policy, including the granting of exceptions for law enforcement officers and for persons acting under the supervision of authorized university personnel, should be addressed to the appropriate chief campus security officer.

Campus Security Act Notice
In accordance with the Crime Awareness and Campus Security Act of 1990 (P.L. 102-26), as amended, and the regulations promulgated thereunder, the university issues its Annual Security Report that describes the security services at each of the university’s divisions and reports crime statistics for each of the campuses. The report is published online at jhu.edu/~security/annual_report.htm. Copies of the report are available from the university’s Security Department, 14 Shriver Hall, 3400 North Charles Street, Baltimore, Maryland 21218-2689, 410-516-4600.

Photograph and Film Rights Policy
The Johns Hopkins University reserves the right from time to time to film or take photographs of faculty, staff, and students engaged in teaching, research, clinical practices, and other activities, as well as casual and portrait photography or film. These photographs and films will be used in such publications as catalogs, posters, advertisements, recruitment and development materials, as well as on the university’s website, for various videos, or for distribution to local, state, or national media for promotional purposes. Classes will be photographed only with the permission of the faculty member.

Such photographs and film—including digital media—will be kept in the files and archives of The Johns Hopkins University and remain available for use by the university without time limitations or restrictions. Faculty, students, and staff are made aware by virtue of this policy that the university reserves the right to alter photography and film for creative purposes. Faculty, students, and staff who do not want their photographs used in the manner(s) described in this policy statement should contact the Office of Communications and Public Affairs.

Faculty and students are advised that persons in public places are deemed by law to have no expectation of privacy and are subject to being photographed by third parties. The Johns Hopkins University has no control over the use of photographs or film taken by third parties, including without limitation the news media covering university activities.

Return of Title IV Funds Policy
The Financial Aid Office is required by federal statute to recalculate federal financial aid eligibility for students who withdraw, drop out, are dismissed, or take a leave of absence prior to completing 60 percent of a payment period or term. The federal Title IV financial aid programs must be recalculated in these situations.

If a student leaves the institution prior to completing 60 percent of a payment period or term, the Financial Aid Office recalculates eligibility for Title IV funds. Recalculation is based on the percentage of earned aid using the following federal return of Title IV funds formula:

\[
\text{Percentage of payment period or term completed} = \frac{\text{Number of days completed up to the withdrawal date}}{\text{Total days in the payment period or term}}
\]

Funds are returned to the appropriate federal program based on the percentage of unearned aid using the following formula:

\[
\text{Aid to be returned} = \left(100\% \times \frac{\text{Unearned aid}}{\text{Total available aid}}\right) - \left(100\% - \frac{\text{Percentage of payment period or term completed}}{100}\right)
\]

Refunds are allocated in the following order:

- Unsubsidized Federal Stafford loans
- Subsidized Federal Stafford loans
- Unsubsidized Direct Stafford loans (other than PLUS loans)
- Subsidized Direct Stafford loans
- Federal Perkins loans
- Federal Parent (PLUS) loans
- Direct PLUS loans
- Federal Pell Grants for which a return of funds is required
- Federal Supplemental Opportunity grants for which a return of funds is required
- Other assistance under this Title for which a return of funds is required (e.g., LEAP)
Trustees and Administration

Trustees
Pamela P. Flaherty, Chair
C. Michael Armstrong, Vice Chair, ex officio
Richard S. Frary, Vice Chair
Gail J. McGovern, Vice Chair
Jeffrey H. Aronson
Janie E. Bailey
Abhiram R. Bhashyam
Paula E. Boggs
Charles I. Clarvit
N. Anthony Coles
Ronald J. Daniels, ex officio
Anthony W. Deering
Andreas C. Dracopoulos
Ina R. Drew
Harvey P. Eisen
Roger C. Faxon
Marjorie M. Fisher
Louis J. Forster
Taylor A. Hanex
Michael D. Hankin
Lee Meyerhoff Hendler
David C. Hodgson
R. Christopher Hoehn-Saric
Frank L. Hurley
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Donald A. Kurz
Ethan D. Leder
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Directions and Maps

**Applied Physics Laboratory**

**From Baltimore and I-95 (southbound):** Take I-95 South from the Baltimore Beltway (I-695) intersection. Go 13 miles and take the Columbia exit (MD Route 32 West). Go 2.5 miles and take the Washington DC exit (U.S. Route 29 South). Go 1.5 miles and take the Johns Hopkins Road exit. APL is on the right, about 0.5 mile. Turn right onto Pond Road, and follow the signs to the Kossiakoff Center parking on the lower lot.

**From Washington and I-95 (northbound):** Take I-95 North from the Capital Beltway (I-495) toward Baltimore. Go 8 miles and take MD Route 216 West (toward Scaggsville). Go 1.2 miles and turn right onto Leishear Road. Go 0.8 mile and turn left onto Gorman Road. Go 0.7 mile and cross the traffic circle and bridge over U.S. Route 29. The road name changes to Johns Hopkins Road. APL is on the right, about 0.5 mile. Turn right onto Pond Road, and follow the signs to the Kossiakoff Center parking on the lower lot.

**From U.S. Route 29:** Proceed on U.S. 29 to the Johns Hopkins Road exits. APL is about 0.5 mile west. Turn right on Pond Road, and follow the signs to the Kossiakoff Center parking on the lower lot.

**Montgomery County Campus**

**From Baltimore (via major arteries):** Take Beltway (I-695) to I-95 South. Continue toward Washington on 95 to the Capital Beltway (I-495). Take 495 West to I-270 North. From 270 North, take the Shady Grove exit (Exit 8). Once on the exit ramp, stay in the left lane. At the light, make a left onto Shady Grove Road. Proceed approximately 0.6 mile to Key West Avenue. Turn right at Key West Avenue and follow to the first intersection. Make a left on Medical Center Drive. The Montgomery County Campus is on the right at 9601 Medical Center Drive.

**From I-95 South:** Take I-95 toward Route 100 East. Exit Route 100 toward Route 1 South. On Route 1, move to the inside lane. At the first light, turn left onto Dorsey Road (Route 103). After about one-third mile on Dorsey Road, turn left onto Douglas Legum Drive. Once on Douglas Legum Drive, the Dorsey Center is on the second floor of the five-story white building with blue windows.

**From I-295 (Baltimore Washington Parkway) North or South:** Exit I-295 toward Route 100 West. Exit Route 100 using the Coca Cola Drive exit. Turn left onto Coca Cola Drive toward Dorsey Road. At the end of Coca Cola Drive, turn right onto Dorsey Road. After about 1 mile on Dorsey Road, turn right onto Douglas Legum Drive. Once on Douglas Legum Drive, the Dorsey Center is on the second floor of the five-story white building with blue windows.

**Homewood Campus**

**From I-95 (southbound) or from I-695 (the Baltimore Beltway):** Take the beltway toward Towson to Exit 25. Take Charles Street south for about 7 miles (when Charles Street splits a block after Loyola College and Cold Spring Lane, take the right fork). As you approach the university and cross University Parkway, continue southbound, but be sure to jog right onto the service road. After you pass the university on the right, turn right onto Art Museum Drive. Just after the Baltimore Museum of Art, bear right at the traffic island onto Wyman Park Drive. Take an almost immediate right through the university gates.

**From I-95 (northbound):** Exit at I-395, then take the exit to Martin Luther King Jr. Boulevard and follow the directions below.

**From Maryland 295 (the Baltimore-Washington Parkway):** Entering Baltimore, the parkway becomes Russell Street. Stay on Russell Street until (with Oriole Park at Camden Yards looming before you) you reach the right-hand exit marked Martin Luther King Jr. Boulevard (look carefully for this; the signs are small). Take Martin Luther King Jr. Boulevard until it ends at Howard Street (remain in one of the middle lanes of Martin Luther King Jr. Boulevard to avoid a premature forced right or left turn). Turn left at Howard Street and proceed about 2 miles. One block past 29th Street (where Howard Street becomes Art Museum Drive), turn left at the traffic island (just before the Baltimore Museum of Art) onto Wyman Park Drive. Take an almost immediate right through the university gates.
From the Jones Falls Expressway (I-83) southbound: Take the 28th Street exit to 28th Street east. Turn left on Howard Street. One block past 29th Street (where Howard Street becomes Art Museum Drive), turn left at the traffic island (just before the Baltimore Museum of Art) onto Wyman Park Drive. Take an almost immediate right through the university gates.

HEAT Center

From Baltimore and Washington, DC, area: Take I-95 North to Exit 85, Route 22, toward Aberdeen/Churchville. Keep left at the fork in the ramp. Turn left onto Churchville Road (Route 22). Turn left onto Technology Drive. The center is on the left-hand side.

Southern Maryland Higher Education Center, St. Mary’s County

From Lexington Park: Take MD Route 235 North approximately six miles to Airport Road. Turn left on Airport Road, and go about one-fourth mile to the Southern Maryland Higher Education Center on the left.

From Calvert County: Take MD Route 4 South. At Solomons, cross the Thomas Johnson Bridge, and continue 4 miles to the stoplight at MD Route 235. Turn right on Route 235, and go north past the Wildwood Shopping Center to Airport Road. Turn left on Airport Road, and go about one-fourth mile to the Southern Maryland Higher Education Center on the left.

From Charles County: Take MD Route 5 South to St. Mary’s County. About 20 miles south of Waldorf, Route 5 branches to the right toward Leonardtown, and the main four-lane road continues straight and becomes MD Route 235. Continue on Route 235 approximately 12 miles to Airport Road. Turn right on Airport Road, and go about one-fourth mile to the Southern Maryland Higher Education Center on the left.

Washington, DC, Center

From points north of the District of Columbia: Take I-95 to 495 (Capital Beltway) to Exit 30, Route 29 South, toward Silver Spring. Follow Route 29 through downtown Silver Spring and cross Georgia Avenue until you reach the circle at the intersection of 16th Street, N.W. Turn left onto 16th Street. Take 16th Street to Scott Circle, bearing to the right to avoid the underpass. Turn right onto Massachusetts Avenue. The center is one block down on the right. An optional route would be to take I-95 to 495 to Exit 33 (Chevy Chase, Connecticut Avenue). Make a left at the exit onto Connecticut Avenue toward Chevy Chase. Follow Connecticut Avenue through Chevy Chase, Van Ness/UDC, Cleveland Park, Woodley Park, across the Taft Bridge and down toward Dupont Circle. Do not go under the tunnel; instead, turn left onto Q Street. Go three blocks to 17th Street and turn right, then go two blocks to Massachusetts Avenue. The center is on the corner of Massachusetts Avenue and 17th Street.

From points south of the District of Columbia: From Vienna, Falls Church, Tyson’s, and Route 66: Take Route 66 into Washington. Go over the Roosevelt Bridge and follow the signs to Constitution Avenue. Make a left turn onto 18th Street, N.W. (there is a left turn arrow). Follow 18th Street through the city and across Connecticut Avenue (you will need to be in the middle lane in order to cross Connecticut Avenue and stay on 18th Street rather than veer left onto Connecticut). Go one more block on 18th Street and you will come to Massachusetts Avenue. Turn right onto Massachusetts Avenue, go one block to 17th Street, and the center is located on the corner of Massachusetts Avenue and 17th Street.

From Alexandria, South Arlington, 495, 95, 395, and Route 1: Take I-495 or 95 to 395. Take 395 (or Route 1) over the 14th Street Bridge and follow the signs for 14th Street, N.W. Take 14th Street to Thomas Circle at M Street. Get in the far right lane and take the outer circle three-quarters of the way around until you reach the turn-off for Massachusetts Avenue (it is just one lane at first, alongside a green railing over a tunnel—you will merge with Massachusetts Avenue traffic). Take Massachusetts Avenue to Scott Circle at 16th Street and follow Massachusetts Avenue around the circle to 17th Street. The center is located on the corner of Massachusetts Avenue and 17th Street. An optional route would be to take 14th Street through Thomas Circle to P Street. Turn left onto P Street and take P Street to 17th Street, where you would turn left. The center is on the corner of 17th Street and Massachusetts Avenue. This route would allow for more street parking options and would avoid traffic backed up on Massachusetts Avenue.

Colonial Parking—1625 Massachusetts Avenue
(202-295-8220)

This garage in the Washington Center is open from 7 a.m. until 8 p.m. weekdays ONLY. While you cannot enter the garage after 8 p.m., you may exit at any time. The parking rate is $6 after 5 p.m.; otherwise, it’s $7 per hour or $14 all day. Enter the garage from Massachusetts Avenue or 17th Street. Because it is sometimes difficult to enter this garage at 5 p.m. (especially on Mondays and Wednesdays), we recommend that you arrive a few minutes early or park at Central Parking (see below).

Central Parking—1225 Connecticut Ave.
(202-223-9225)

Parking is also available at the Central Parking garage, located at the above address. The entrance to the garage is on N Street between 17th and 18th streets. The garage is open from 6:30 a.m. until 11 p.m. You must validate your parking ticket at the Washington Center front desk in order to
obtain the $5 JHU discounted rate. This rate is in effect only after 5 p.m. on weekdays.

**Parking on Saturdays—1333 New Hampshire Avenue (202-298-7076)**

The closest parking garage, located at 1333 New Hampshire Avenue (entrance on 19th Street), does not open until 9 a.m. on Saturdays ($10 flat rate) and is several blocks from the Washington Center. However, street parking is available nearby. Students are encouraged to arrive early to find a parking space within close vicinity of the building. While metered parking is not enforced on weekends, students should read all street signs to ensure that parking is allowed. Johns Hopkins University will not be responsible for parking violations.

**Metro**

Many Washington Center students travel to and from class on the Metro. The center is conveniently located near two Metro stops: Dupont Circle (south exit) on the red line (two blocks away) and Farragut West on the blue and orange lines (five blocks away).
The Johns Hopkins University
APPLIED PHYSICS LABORATORY
APL EDUCATION CENTER
11100 Johns Hopkins Road
Laurel, MD 20723-6099
443-778-6510 (Baltimore)
240-228-6510 (Washington, DC)
The Johns Hopkins University
MONTGOMERY COUNTY CAMPUS
9601 Medical Center Drive
Rockville, MD 20850-3332
301-294-7070
The Johns Hopkins University
WHITING SCHOOL OF ENGINEERING
DORSEY STUDENT SERVICES CENTER
Dorsey Business Park
6810 Deerpath Road, Suite 100
Elkridge, MD 21075
410-516-2300
800-548-3647
The Johns Hopkins University
SOUTHERN MARYLAND HIGHER EDUCATION CENTER
44219 Airport Road
Wildwood Technology Park
California, MD 20619
301-737-2500
The Johns Hopkins University
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Century Center II Building, Suite 1200
2461 South Clark Street
Arlington, Virginia 22202
240-228-2912
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