A message to engineers, scientists, and others interested in continuing their professional development:

Welcome to the Engineering and Applied Science Programs for Professionals (EPP) at Johns Hopkins University. The Whiting School of Engineering has earned a reputation for excellence among top schools in the nation for providing advanced engineering education for working professionals. I invite you to explore our catalog and discover the many programs, certificates, and courses that we offer, both online and throughout the Baltimore-Washington region.

Our mission is to cultivate and impart knowledge in a range of engineering disciplines—fully supported by the outstanding faculty, students, and industry leaders who comprise the Johns Hopkins Engineering community. Since 1912, Johns Hopkins University has been at the vanguard of engineering education. From EPP’s inception in 1966, our focus has been to make that engineering education accessible to our community’s workforce. We have since expanded our programs to offer 14 master’s degree program areas as well as a number of advanced certificates.

Our growth and success are a result of our commitment to provide an education that balances the most advanced theory with current industry practices. Among our faculty are outstanding practitioners and researchers in the region’s leading corporate and government organizations. As industry experts, they enrich our courses with their unique experiences and give our students the practical knowledge they need to keep abreast of current technologies and become innovative leaders. In addition, our faculty stresses the mastery of theory, empowering students to apply what they’ve learned with a sound understanding of their fields.

This year we’ve continued to increase our online course offerings in a number of program areas. A master’s degree in Environmental Planning and Management went fully online last fall. In addition, I’m pleased to announce that, within our Technical Management program, we will be offering a new concentration in “Technical Innovation Management.” Be sure to visit our website to check for these and other program updates at www.epp.jhu.edu.

At Johns Hopkins, we believe that engineering and innovation are inseparable. In line with our vision statement, “Leadership Through Innovation,” we believe that our advanced degrees give our graduates the tools to be the innovators and leaders of their fields.

I invite you to join the Johns Hopkins Engineering community—and challenge you to become both a leader and an innovator in your field.

Nicholas P. Jones
Dean, Whiting School of Engineering
Academic and Registration Calendar

Academic Year 2008–2009

<table>
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<tr>
<th>Important Semester Dates:</th>
<th>Summer 2008</th>
<th>Fall 2008</th>
<th>Spring 2009</th>
</tr>
</thead>
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<tr>
<td>First Day of Classes</td>
<td>June 2</td>
<td>September 3</td>
<td>January 26</td>
</tr>
<tr>
<td>Last Day of Classes</td>
<td>August 23</td>
<td>December 13</td>
<td>May 9</td>
</tr>
<tr>
<td>Graduation Application Deadlines</td>
<td>June 15</td>
<td>September 15</td>
<td>January 15</td>
</tr>
<tr>
<td>Holidays</td>
<td>July 4</td>
<td>November 26-30</td>
<td>March 16-22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Registration Deadlines:</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Registration Opens</td>
<td>March 27</td>
<td>June 26</td>
<td>October 30, 2008</td>
</tr>
<tr>
<td>Registration Closes</td>
<td>May 27</td>
<td>August 22</td>
<td>January 16, 2009</td>
</tr>
<tr>
<td>Final Day to Add</td>
<td>2nd class meeting</td>
<td>September 16</td>
<td>February 7</td>
</tr>
<tr>
<td>Withdraw/Audit Deadline</td>
<td>9th class meeting</td>
<td>November 28</td>
<td>April 13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Online Course Deadlines:</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Deadline to Register</td>
<td>May 21</td>
<td>August 22</td>
<td>January 16</td>
</tr>
<tr>
<td>Orientation for First-Time Students</td>
<td>May 27–June 1</td>
<td>August 27–September 2</td>
<td>January 19-25</td>
</tr>
<tr>
<td>Final Day to Add</td>
<td>June 9</td>
<td>September 10</td>
<td>February 3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tuition Payment Deadlines</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>June 16</td>
<td>September 17</td>
<td>February 9, 2009</td>
<td></td>
</tr>
<tr>
<td>There will be a $125 late fee if tuition is not paid by due date.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

New Student Advising Session:

<table>
<thead>
<tr>
<th>Dorsey</th>
<th>APL</th>
<th>APL</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 27</td>
<td>August 25</td>
<td>January 21, 2009</td>
</tr>
<tr>
<td>4:30–6:00 pm</td>
<td>4:30–6:00 pm</td>
<td>4:30–6:00 pm</td>
</tr>
<tr>
<td>MCC</td>
<td></td>
<td>MCC</td>
</tr>
<tr>
<td>August 26</td>
<td></td>
<td>January 20, 2009</td>
</tr>
<tr>
<td>5:00–6:30 pm</td>
<td></td>
<td>5:00–6:30 pm</td>
</tr>
</tbody>
</table>

Whiting School Graduate Ceremony is Wednesday, May 20, 2009.
University Commencement Day is Thursday, May 21, 2009.
Whiting School of Engineering
Engineering and Applied Science Programs for Professionals
Johns Hopkins University
Dorsey Student Services Center
6810 Deerpath Road, Suite 100
Elkridge, MD 21075
800-548-3647
epp@jhu.edu
www.epp.jhu.edu

General Information and Requests
Admissions/Registration (Dorsey Student Services Center) .................. 410-516-7904
Fax Number ........................................ 410-516-7881

Education Centers
Applied Physics Lab (from Baltimore) ................................................ 443-778-6510
(from Washington) .................. 240-228-6510
Dorsey Student Services Center ........................................ 410-516-7904
Higher Education and Applied Technology Center (HEAT) ........................ 800-548-3647
Homewood Campus ........................................ 410-516-8000
Montgomery County Campus ........................................ 301-294-7070
Southern Maryland Center ........................................ 800-548-3647
Washington D.C. Center ........................................ 800-548-3647

Student Services
Bookstore (Barnes & Noble Johns Hopkins) ................................. 410-662-5850
Book Center (Montgomery County Campus) ................................ 301-721-9300
Career Services ................................................ 410-516-9730
Disability Services ................................................ 410-516-7905
Financial Aid (146 Garland Hall) ................................................ 410-516-8028
International Office ................................................ 410-516-1013
University Registrar (75 Garland Hall) ........................................ 410-516-8083
Student Accounts (EPP) ................................................ 410-516-7904
Student Accounts (Homewood) ................................................ 410-516-8158
Transcripts (75 Garland Hall) ................................................ 410-516-7088
Veterans Certification (75 Garland Hall) ........................................ 410-516-7071

Online Information
Catalog ................................................ http://catalog.epp.jhu.edu
Application for Admission ................................................ www.epp.jhu.edu/apply/
Course Schedule ................................................ www.epp.jhu.edu/schedule
EPP Forms ................................................ www.epp.jhu.edu/student-forms

Textbooks
Barnes & Noble ................................................ http://johns-hopkins.bkstore.com
Reiter’s ................................................ http://jhu.textbooks.com

The Johns Hopkins University (276–280) is published four times a year by The Johns Hopkins University, Office of Design and Publications, 901 S. Bond Street, Suite 540, Baltimore, Maryland 21231. Issued in January, August and twice in April. Periodicals postage paid at Baltimore, Maryland, and additional mailing offices. New Series 2008, No. 2, Vol. 127, April 2008. Postmaster: Send address changes to The Johns Hopkins University, Professional Programs in Engineering and Applied Science, 6810 Deerpath Road, Suite 100, Elkridge, Maryland 21075.

On the covers
(Front cover, left to right) Student Jack Lum (Electrical and Computer Engineering), alumnus Sheri Kujawa (Applied and Computational Mathematics), student Michael Chang (Computer Science), and instructor Steve Bien (Systems Engineering).
(Back cover, left to right) Alumnus Etsubisat Beshah (Civil Engineering), student Jack Lum (Electrical and Computer Engineering), and instructor Chris Ucera (Systems Engineering).
Engineering Administration

Whiting School of Engineering
Nicholas P. Jones, Dean

Engineering and Applied Science Programs for Professionals
Allan W. Bjerkaas, Associate Dean

APL Education Center
Ellen Elliott, Director

Montgomery County Center
Richard Scott, Director

Graduate Program Administration
James C. Spall
Program Chair, Applied and Computational Mathematics
Russell L. McCally
Program Chair, Applied Biomedical Engineering
Harry K. Charles Jr.
Program Chair, Applied Physics
Konstantinos Konstantopoulos
Program Chair, Chemical and Biomolecular Engineering
Annalingam Anandarajah
Program Chair, Civil Engineering
Ralph D. Semmel
Program Chair, Computer Science
Dexter G. Smith
Program Chair, Electrical and Computer Engineering

Hedy V. Alavi
Program Chair, Environmental Engineering, Science and Management
Ralph D. Semmel
Program Chair, Information Systems and Technology
Robert C. Cammarata
Program Chair, Materials Science and Engineering
K. T. Ramesh
Program Chair, Mechanical Engineering
Kenneth A. Potocki
Program Chair, Systems Engineering
Kenneth A. Potocki
Program Chair, Technical Management
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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.
Current co-instructor Michel Reece (far left) looks on as John Penn speaks to students (from left) Niral Patel, Dimitrios Loizos, and Cosburn Wedderburn.

Brenda Knox, director of Distance Education, capturing multimedia for EPP online course offerings.
The Johns Hopkins Distinction

Since the beginning of the 20th century, The Johns Hopkins University has been a leader in providing working adults with opportunities to continue their engineering education on a part-time basis. The Whiting School of Engineering’s Engineering and Applied Science Programs for Professionals maintains as its core mission a dedication to provide a community of excellence to professionals whose personal and career goals include continuing education.

“Where Excellence Surrounds You” is how Engineering Programs for Professionals defines its commitment to students. The Johns Hopkins community of excellence means that students attend classes taught by faculty who are at the top of their respective fields, receive inspiration from the high caliber of classroom interaction, and have access to exemplary administrative services. Consequently, the programs are among the largest such programs in the nation, attesting to the students’ enthusiasm for the programs as well as the Whiting School’s concern for engineers and scientists who pursue study after working hours.

As they have grown, Engineering Programs for Professionals have extended their reach into the surrounding community, providing students a variety of classroom locations, as well as selected online courses, suited to their academic needs and busy schedules. Graduate students take courses at the Homewood campus in Baltimore, the Applied Physics Laboratory in Laurel, the Montgomery County Campus in Rockville, the Dorsey Center near Baltimore/Washington International Thurgood Marshall Airport, the Southern Maryland Higher Education Center in St. Mary’s County, the Washington Center in Washington, D.C., and the Higher Education and Applied Technology Center in Harford County. Students take courses during the late afternoon and evening, on Saturday, or online.

Accredited by the Middle States Commission on Higher Education, Johns Hopkins University is privately endowed. Founded in 1876 as the first American educational institution dedicated to research, it established the model for advanced study in this country.

Nine divisions of the University grant degrees. They are the Whiting School of Engineering, the Krieger School of Arts and Sciences, and the School of Education on the Homewood campus; the schools of Medicine and Nursing and the Bloomberg School of Public Health adjacent to The Johns Hopkins Hospital; the Peabody Institute and the Carey Business School in downtown Baltimore; and The Paul H. Nitze School of Advanced International Studies based in Washington, D.C. (with foreign study centers in Bologna, Italy, and Nanjing, China). The 10th division of the University is the Applied Physics Laboratory (APL), a research institute located in Laurel, Maryland.

Whiting School of Engineering

Engineering began at Johns Hopkins in 1913 when University leaders decided to establish a curriculum that focused on professional education but included significant exposure to the liberal arts and scientific inquiry. Fostering interdisciplinary creativity, this unique approach to engineering education was emulated by many engineering schools around the country.

Some seven decades later, Johns Hopkins underscored its commitment to engineering distinction by establishing the Whiting School of Engineering as a separate division on the Homewood campus.

The School consists of the following departments: Applied Mathematics and Statistics, Chemical and Molecular 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 www.jhu.edu. Admission information for full-time undergraduate education is available from the Office of Admissions, Mason Hall, 3400 N. Charles Street, Baltimore, Maryland 21218, 410-516-8171. For full-time graduate education, the student 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 received graduate and undergraduate degrees through part-time study, achieving personal and professional goals without interrupting their careers.

Today, the Engineering and Applied Science Programs for Professionals (EPP) fosters a community of excellence for students and faculty alike. This community extends into the surrounding region, in which the programs have created partnerships with a number of companies for unique learning experiences.

Students take courses that are continually updated for relevance, addressing industry trends and the latest advances in engineering and applied science fields. Classes are scheduled at convenient times in late afternoon, evening, and on Saturday. Each year, EPP offers an increasing number of courses online to meet the needs of busy students.
**Graduate Programs**

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

Graduate programs leading to master’s degrees are offered at the locations shown in the table below.

Almost all courses are scheduled either in the late afternoon or evening Monday through Friday and 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, but not both. Nearly every engineering school, including the Whiting School, chooses to have its basic programs accredited by ABET.

<table>
<thead>
<tr>
<th>Location</th>
<th>Graduate Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homewood</td>
<td>Full program offerings in chemical and biomolecular engineering; civil engineering; environmental engineering, science and management; and materials science and engineering. Selected courses in mechanical engineering.</td>
</tr>
<tr>
<td>Applied Physics Laboratory</td>
<td>Full program offerings in applied and computational mathematics, applied biomedical engineering, applied physics, computer science, electrical and computer engineering, information systems and technology, materials and condensed matter, nanotechnology, photonics, systems engineering, technical management, and telecommunications and networking. Selected courses in bioinformatics; environmental engineering, science and management; materials science and engineering; and mechanical engineering.</td>
</tr>
<tr>
<td>Montgomery County Campus</td>
<td>Full program offerings in bioinformatics; computer science; electrical and computer engineering; environmental engineering, science and management; information systems and technology; systems engineering; technical management; and telecommunications and networking. Selected courses in applied and computational mathematics and applied biomedical engineering.</td>
</tr>
<tr>
<td>Dorsey Center</td>
<td>Full program offerings in mechanical engineering. Selected courses in applied and computational mathematics; applied biomedical engineering; applied physics; civil engineering; computer science; electrical and computer engineering; environmental engineering, science and management; information systems and technology; photonics; systems engineering; technical management; and telecommunications and networking.</td>
</tr>
<tr>
<td>Southern Maryland Higher Education Center</td>
<td>Systems engineering and technical management.</td>
</tr>
<tr>
<td>Washington DC Center</td>
<td>Selected courses in environmental engineering, science and management.</td>
</tr>
<tr>
<td>Higher Education and Applied Technology Center</td>
<td>Selected courses in environmental engineering, science and management, and systems engineering.</td>
</tr>
<tr>
<td>Online</td>
<td>Full program offerings in bioinformatics and environmental planning and management. Selected courses in computer science, electrical and computer engineering, information systems and technology, and environmental engineering, science and management.</td>
</tr>
</tbody>
</table>
Degrees and Certificates

The Johns Hopkins University confers a variety of degrees and certificates upon students in the Whiting School of Engineering. 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 and science, environmental planning and management, information systems and technology, systems engineering, and technical management.

A joint degree in bioinformatics is offered by the Engineering and Applied Science Programs for Professionals and the Krieger School of Arts and Sciences Advanced Academic Programs. The description of this degree can be found under Graduate Programs under the Bioinformatics program.

Master of Engineering

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

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. This certificate is available in several areas including electrical and computer engineering; environmental engineering, science and management; technical management; and systems engineering.

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.

Admission Requirements

The Whiting School of Engineering encourages all students who have serious academic interests to apply. Qualified students may structure their course work 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.

Master’s Degree Candidate

The program consists of 10 courses planned in consultation with an adviser. Note that the joint MS degree in Bioinformatics 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.

Students must complete the master’s degree within five years from the start of the first course in the student’s program.

Advanced Certificate for Post-Master’s Study Candidate

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 and/or breadth 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 adviser. 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 admission committee review.
General Information

Admission Requirements

submit a formal application, a nonrefundable $75 application
gram or to take courses as Special Students, applicants must

tions on course applicability toward a degree are made on an
is subsequently accepted as a degree candidate. Determina-
count toward fulfillment of degree requirements if the student
as well as specific course prerequisites in order to enroll.
registering for EPP courses.
enrolled in a graduate program at another university and are
program in which they have applied to be a Special Student.
technical disciplines and meet admission prerequisites for the
latter half of their studies or hold graduate degrees in relevant
point average of at least 3.0 on a 4.0 (B or above) scale in the
of undergraduate study. Applicants must have earned a grade
ally accredited college or university or be in the last semester
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 A or B are countable toward
the Advanced Certificate for Post-Master’s Study.

Courses taken for the Advanced Certificate for Post-Mas-
ters Study may be counted toward a master’s degree.

Graduate Certificate Candidate

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. The
program area of study specifies the selection and number
of applicable courses. 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.

Students must meet the general master's degree admis-
sion 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 adviser 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 A
or B are countable toward the Graduate Certificate.

Special Student

The general requirement for admission as a Special Student is
that the applicant must hold a bachelor's degree from a region-
ally 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
enrolled in a graduate program at another university and are
registering for EPP courses.

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. Determina-
tions on course applicability toward a degree are made on an
individual basis.

Application Procedures

To be considered for admission to a degree or certificate pro-
gram 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 tran-
scripts of all college studies, and any other documents specified
by particular 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 graduates of the Whiting School
of Engineering.

In addition to being included in this catalog, the applica-
tion is available online at www.epp.jhu.edu/graduation-
application. Complete instructions are available on the web
site.

An application for admission is not reviewed by an admis-
sions 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. Failure to provide all official tran-
scripts, supporting documents, and application fee will delay
review of the application. Please allow 4–6 weeks for applica-
tion 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 applica-
tion 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 following 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 EPP program establishes no claim or priority
for admission to other divisions of the University.

International Applicants

The Engineering and Applied Science Programs for Profes-
sionals offers part-time graduate study in the evenings and
weekends at seven locations throughout the Maryland-Wash-
ington area. The United States Immigration and Naturaliza-
tion Service regulations require students with F-1 visas to
be enrolled in full-time, degree-seeking program. Students
enrolled full-time with EPP must take three courses or more
each fall and spring semester.

As EPP does not provide on-campus housing or financial
support for graduate international students, applicants need-
ing 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 school’s international office for information
on how to transfer to another SEVIS school.
General Information

The EPP office 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 Johns Hopkins University, Office of International Student and Scholar Services, theworld@jhu.edu.

International Credential Evaluation

Applicants who hold degrees or have earned credits from non-U.S. institutions must have their academic records evaluated by the 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 EPP, 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, New York, 10113-0745
Telephone: 212-966-6311
Fax: 212-966-6395
E-mail: info@wes.org

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 EPP 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 on the Admission Requirements page. 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, VISA, MasterCard, Discover, tuition remission, or company contract accompanied by purchase order. We will not defer payment for companies that provide tuition reimbursement at the end of the term. In this instance, students must pay tuition themselves and be reimbursed by their employer. If payment is not made by the deadline date, a late payment fee of $125 will be incurred.

If you have registered and have not paid your balance, an email statement will be sent to you on the 16th of each month with the balance due the University. 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 email. Changes in circumstances may have an effect on the amount that you are responsible to pay, for instance, adding or dropping courses, late registration, or late payment fees.

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

Course Schedule

The EPP course schedule, which lists the day, time, location, and instructor for each course, is available on the web at www.epp.jhu.edu 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 EPP 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.

Course Credit

Credit hours are not assigned for graduate level courses (400-level and above).

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 the EPP website (www.epp.jhu.edu) and following the registration link. Students must establish a JHED account in order to use web registration; instructions are available on the opening page.

Registering for Online Courses

Initial contact and instructions for online courses will be delivered via email prior to the first day of classes each term. Therefore, it is the responsibility of students registering for online courses to supply a current and active email address and an alternate contact method, such as work and/or home phone numbers, on the registration form for each term.

Late Registration

Students may register after the beginning of a term if necessary. However, students enrolling in their first JHU EPP online course must be registered no later than a week and a half prior to the first day of classes in order to attend a mandatory online orientation prior to the start of the term. 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. See the Registration Deadlines section of the Facilities and Student Services page for a detailed description of the orientation and student participation requirements. Although there is no fee for late registration, students who delay registering until these times may find course selection severely restricted. Late registrations may be faxed to 410-516-7881.

New Applicants
An applicant who has not received an admission decision prior to the start of the semester must attend an advising session. Dates of advising sessions are listed on the academic calendar. Advising sessions are scheduled just prior to the start of each semester to give applicants the opportunity to meet with an adviser to discuss the applicant’s qualifications for the program. Depending upon prior coursework taken, the 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.

Interdivisional Registration
With approval of their advisers, 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 on the EPP registration form. Please note that tuition rates vary by division.

Students in other divisions of Johns Hopkins may register for courses in Engineering Programs for Professionals, subject to the regulations of their home divisions and availability of space. The form requesting registration is available at the Homewood Registrar's Office, 75 Garland Hall.

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 alternate 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 strongly urged to limit their course load to no more than two per term.

Auditors
Students may register as auditors with the approval of the appropriate program adviser. 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 file the “add/drop” form before the deadline listed for each term in the Academic and Registration Calendar. There is no reduction in fees when auditing a course.

Adding and Dropping Courses
Courses may be added or dropped online or by submitting the “add/drop” form available at www.epp.jhu.edu and at the instructional sites. Deadlines for completing this procedure are given in the Academic and Registration Calendar. 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 on the Tuition and Fees page.

Textbooks
Texts are available during advising sessions and during the first two weeks of classes at the site where the student is registered. Textbooks can also be purchased online:

For Montgomery County and the DC Center
Books can be found online at Reiter's www.jhutextbooks.com

For All Other Locations and Online Courses
Books can be found online at Barnes & Noble http://johns-hopkins.bkstore.com

Academic Regulations
Following are the general requirements governing study in Engineering and Applied Science Programs for Professionals 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.

Advisers and Program Planning
Students are assigned an adviser when accepted. In addition, students in most master’s degree and certificate programs are required to submit a Program Planning form for their adviser’s approval. The Program Planning form provides students an opportunity to structure their course work according to their educational objectives and to meet degree requirements. Submission of the form confirms the student’s acceptance of admission and his or her intention to begin study. Courses that deviate from the program plan and have not been approved by an adviser may not count toward degree requirements. The
Program Planning form may be accessed on the EPP website by clicking “forms” from the homepage.

Students in programs that do not require Program Planning forms are urged to consult their adviser prior to registration for courses.

If a newly admitted student fails to return the Program Planning form when requested, it is assumed that the student does not wish to enter the program at that time. Even if the form is returned but the student fails to enroll within one year, it is necessary to reapply.

**Academic Standing**

**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. 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

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

**Certificate or Advanced Certificate for Post-Master’s Study**

No grade of C can be counted toward a 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 adviser must approve the course(s) as appropriate to the plan of study; and
- 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 Engineering and Applied Science Programs for Professionals, Dorsey Student Services Center at least one term 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 Engineering Programs for Professionals admissions office in writing and request a leave of absence for a specified period of time. The appropriate program chair will make the decision 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, 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 may not count toward requirements if they are not completed within the time allowed for degree completion.

**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 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 in the Engineering and Applied Science Programs for Professionals. 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 $260 per course.

**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. The graduation application is available at [www.epp.jhu.edu/graduation-application](http://www.epp.jhu.edu/graduation-application).

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 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.

All degrees are conferred in May regardless of when degree requirements are completed and regardless of the date of recommendation by the Graduate Committee. 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 receive bills for graduation in early spring. For graduation fees, see the Tuition and Fees page.

Johns Hopkins diplomas indicate the degree and major (e.g., Master of Science–Computer Science) without identifying the student’s concentration or option.

**Honors**

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

**Grading System**

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

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 a laboratory, both the lecture and laboratory work must be retaken unless the instructor indicates otherwise.

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/her control. In consultation with the instructor, the student completes a Resolution of Incomplete form in which he or she states the reasons for requesting the incomplete and plans for resolving it. The form must be signed by the instructor. The student and instructor each retain a copy; the remaining copies are attached to the grade roster and are sent by the instructor to the Registrar. An incomplete submitted without this form is recorded as an F on the student’s academic record. Resolution of Incomplete forms are included with the final grade roster. They may also be obtained at any of the instructional site offices.

The Resolution of Incomplete form requires that the instructor specify the grade that the student would receive in the course if the incomplete work were not completed. (This grade may be, but need not be, an F.) Thus, if the course work is not completed, the student receives the “reversion” grade; that is, the grade that reflects work completed to that point. A $60 change of grade fee must be mailed to the EPP 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. For academic year 2008–2009, the dates by which final grades for incomplete work must be resolved are:

<table>
<thead>
<tr>
<th>Semester</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer term</td>
<td>October 2</td>
</tr>
<tr>
<td>Fall semester</td>
<td>February 23</td>
</tr>
<tr>
<td>Spring semester</td>
<td>July 1</td>
</tr>
</tbody>
</table>
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 EPP Student Services Center staff if their names are reported so they can take corrective action. These early reports are for the benefit of students and their advisers and are not part of the permanent record.

Following the end of each term, the Office of the Registrar mails a grade report to each enrolled student. Grades are also available online at https://isis.jhu.edu/sswf. These reports CANNOT be requested by telephone or personal inquiry. Students who desire additional copies of their grade reports or who want their transcripts sent to other institutions should make arrangements with the Office of the Registrar, 75 Garland Hall, 410-516-7088.

Grade Appeals
Student concerns regarding grades must be first discussed thoroughly with the 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 attend regularly all courses in which they are enrolled. Although EPP 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 EPP staff to inform students of the cancellation, a makeup time for the class (if available), and information regarding assignments. If an instructor informs the EPP office of a class cancellation, with enough lead time, phone calls will be made to students.

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

Academic Misconduct
This section summarizes the policy on academic misconduct described at engineering.jhu.edu/include/content/pdf-word/academic-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 of the Engineering Programs for Professionals. 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 web site noted above.

Copyright Violations
Copying, downloading or distributing music, videos, software, games or other copyrighted materials without permission of the owner is a violation of University policy, which will be submitted for disciplinary action, and is a serious violation of federal law.

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 JHU’s Office of Information Technology updates its policies frequently, please visit the JHU IT website (http://www.it.jhu.edu/) for the latest information on usage, security, as well as the “Jumpstart” guide for student policies: http://jumpstart.jhu.edu/policies.php.

The following includes key elements of the policy, which is posted in all EPP 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 JH 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 $2,600 per course, unless otherwise noted. The tuition for 200-level courses is $1,430. 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 410-516-7960.

**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 a bill from the office of Student Accounts.

**Late Tuition Payment Fee**
Tuition payment due dates are indicated on the academic calendar. If payment is received after the due date, a late payment fee of $125 will be incurred.

**Transfer Credit Fee**
Graduate courses completed at another school and approved for transfer are assessed a fee of $260 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 EPP 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 suspended or dismissed for disciplinary reasons.

Tuition refunds are made in accordance with the schedule below.

<table>
<thead>
<tr>
<th>Drop Date</th>
<th>Refund</th>
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<tbody>
<tr>
<td>Prior to third class meeting</td>
<td>100%</td>
</tr>
<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>

Students who are enrolled at the Johns Hopkins University for the first time and who are receiving federal student financial aid are subject to a separate refund policy during their first period of enrollment. Refer to Title IV Refunds on the Financial Aid page for further information.

**Financial Aid and Veterans Benefits**

Federal financial aid in the form of grants and student loans is available to part-time undergraduate and graduate degree candidates who are enrolled in two or more courses per term (or the equivalent of at least six credits). Before receiving federal or other financial aid, students must establish financial need by completing the Free Application for Federal Student Aid (FAFSA) and a Hopkins application. These forms are available from the Office of Student Financial Services, 146 Garland Hall, call 410-516-8028 or e-mail fin_aid@jhu.edu or download from www.jhu.edu/finaid/elecserv. Students can also file the FAFSA electronically with FAFSA on the Web at www.fafsa.ed.gov. A copy of your and your spouse’s (if applicable) most current federal income tax return is also required.

The FAFSA should be submitted no later than March 1 for the upcoming academic year. Students should indicate on the aid form that they will be attending the Johns Hopkins University Whiting School of Engineering, code #E00473.
and should identify themselves as students in the Engineering and Applied Science Programs for Professionals when they call or write the Office of Student Financial Services.

Annual application and submission of the FAFSA is required for all federal programs. In accordance with federal regulations, only U.S. citizens and permanent residents who have been accepted into a degree program or who enroll as special students for one academic year will be considered for financial aid. Students on academic probation are not eligible to receive financial aid.

**Types of Financial Aid**

**Federal Pell Grants**—Undergraduate students working toward their first baccalaureate degree and taking a minimum of six credits per semester are eligible for consideration. Those students who are less than half-time may also be eligible for the Federal Pell Grant. Applicants must be U.S. citizens or permanent residents, and should submit the Free Application for Federal Student Aid to be considered for the upcoming academic year.

**Federal Direct Student Loans**—Undergraduate and graduate students enrolled in a degree program for a minimum of six credits or two classes per semester may apply for a Federal Direct Student Loan which carries a fixed interest rate of 6.8 percent. All subsidized Federal Direct Student Loan applicants must show eligibility based on a need analysis and must complete the FAFSA, a Hopkins application, and submit tax returns and W-2s. If you wish to apply for an unsubsidized loan (interest accrues while you are in school), follow the same directions. Applicants must be U.S. citizens or permanent residents. Maximum annual loan limits for the subsidized and unsubsidized Federal Direct Student Loan programs:

**Subsidized Program**
- Independent Undergraduate: $5,500
- Third/fourth year: $5,500
- Special Student: $5,500
- Graduate: $8,500

**Unsubsidized Program**
- Independent Undergraduate: $5,000
- Third/fourth year: $5,000
- Special Student: $5,000
- Graduate: $10,000

Loans are processed by Hopkins and students are mailed a promissory note. Funds are credited to the student’s account.

**Federal Perkins Loan**—Undergraduate and graduate students who demonstrate financial need may apply for the Federal Perkins Loan. Special students are allowed financial aid for two semesters. The Federal Perkins Loan program is administered by Hopkins. The current rate of interest is 5 percent.

**Scholarships**—A select number of scholarships are available for part-time graduate students. Awards are generally made on the basis of merit and financial need. To be eligible for need-based scholarship funds, students must establish financial need by completing the FAFSA and a Hopkins application.

**Outside Scholarships**—Outside scholarships from private organizations can be an additional source of aid. Information about these scholarships is available through the financial aid web page, [www.jhu.edu/finaid](http://www.jhu.edu/finaid) (click on FastWeb), publications in local libraries and bookstores, and community organizations.

**More Information**—Students interested in financial aid may find more detailed information in the graduate brochures on financial assistance available from the Office of Student Financial Services in Garland Hall or on our web page [www.jhu.edu/finaid](http://www.jhu.edu/finaid).

**Title IV Refunds**

The Higher Education Act stipulates that first-time enrolled students receiving federal student aid who withdraw from school shall obtain a pro-rated refund, which must first be applied to all federal student loans and grants. The refund extends to all university charges if the student withdraws at any point up to 60 percent of the first enrollment period. Students who meet these criteria should identify themselves when they contact the part-time programs office about their intention to withdraw. A copy of the federal refund policy applicable to such students will be provided along with the student’s refund. The pro-rated refund policy does not apply to students who are employees of the federal government and are attending EPP classes with federal tuition remission funding.

**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 based on the table below.

<table>
<thead>
<tr>
<th>Credits per term</th>
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<tbody>
<tr>
<td>12</td>
<td>Full-time</td>
</tr>
<tr>
<td>9-11</td>
<td>Three-quarter time</td>
</tr>
<tr>
<td>6-8</td>
<td>One-half time</td>
</tr>
<tr>
<td>1-5</td>
<td>Payments cover only a portion of assigned fees</td>
</tr>
</tbody>
</table>

Note that credits are not assigned to 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:
General Information

Facilities and Student Services

**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 either the Department of Veterans Affairs or the University.

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

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

**Transfers**—When transferring from another college or university, the veteran must obtain a Request for Change of Program or Place of Training Form (DVA Form 22-1995) from either the Department of Veterans Affairs or the University, and must submit the completed form to the Registrar’s Office in Garland Hall at the University.

**Re-enrollment**—A student who received veterans benefits while attending the University during the preceding semester or summer session, and who plans to re-enroll with no change of objective, must advise the Registrar when submitting registration materials that he or she wishes to be recertified under the provisions of the original DVA Form 22-1990.

Students receiving veterans benefits must pursue a program of courses which leads toward the exact objective (normally a degree or certificate) indicated on the original DVA application. Any change in program or objective requires submission of a Request for Change of Program (DVA Form 22-1995). Veteran students are required to advise the Registrar immediately of any change in their program or status which might affect the amount of their monthly payment from the DVA. Failure to do so will cause the Department of Veterans Affairs to seek restitution from the veteran for the overpayment of benefits.

**Standards of Progress**—Continuation of DVA payments is dependent upon the veteran meeting the academic standards established by the University for all students—veterans and non-veterans alike. The veteran must also meet any standards of progress that are or may be established by DVA regulations. If the student fails to meet these standards, benefits will be suspended until the DVA completes a review of the student’s progress and determines that the benefits may be resumed.

Facilities and Student Services

The Engineering and Applied Science Programs for Professionals of the Whiting School are offered at the Homewood campus in Baltimore, the Applied Physics Laboratory (APL) in Laurel, 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, D.C., the Higher Education and Applied Technology Center (HEAT) in Harford County, and fully online. The educational and student facilities and services provided at each location are described below.

**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 library centers, 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 upon written request of the student at no charge. Requests for transcripts should be addressed to the Office of the Registrar, 75 Garland Hall. Transcripts may also be ordered online from http://www .studentclearinghouse.org for a fee. For more information about each of these options, see http://www.jhu.edu/~registr/transcript.html.

**International Student Services**

Students may contact the International Student & Scholar Services at 410-516-1013. For more details please refer to the Admission Requirements section.

**Services for Students with Disabilities**

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 disability services coordinator, at 410-516-7905 or at epp@jhu.edu.

In order to receive accommodations, it is important to provide to 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 Engineering Programs for Professionals 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, contact Peggy Hayeslip, director, ADA Compliance and Disability Services, 410-516-8949, or phayeslip@jhu.edu.

**Career Services**

Career Services is dedicated to assisting current students and alumni understand their career choice and help them in their professional advancement in their chosen career. Partnering
with employers and past alumni, the Office of Career Services seeks to provide cutting-edge programming and services on topics such as resume building, career and life balance, networking, marketing yourself, portfolio development, and more. Career Services is not just for those who are currently job searching, but also for those seeking to advance with their current employer. To make an appointment, please call 410-516-9730 or email careerservices@jhu.edu. To learn more about our services, please visit us at www.careerservices.jhu.edu.

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 class and campus closing, 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: 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 web sites. You may find your login ID and initiate your account by going to http://jhed.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, refer to http://jumpstart.jhu.edu/policies.php.

JHEM – JHEM (Johns Hopkins Enterprise Messaging) is the official e-mail system recognized and used by the University to send campus news and announcements. All students are provided with a JHEM account and are required to set up their mailbox. If you have another e-mail account and prefer to use it, you can forward JHEM mail to that account. All e-mail sent to and from the University e-mail systems is scanned for viruses. You may access your JHEM e-mail account via a web interface at https://my.johnshopkins.edu or by using pop or imap protocols through an e-mail client such as Netscape Messenger, Outlook Express, or Eudora. Instructions are available online at http://it.jhu.edu/email/jhem/info/clientsetup.html.

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 Institutions.

Some features of JShare include, but are not limited to:
- 500 megabytes 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 Institutions
- Ability to email files as links to reduce the load on email systems
- Ability to create and maintain personal web sites

There are two primary ways to connect to JShare. The most comprehensive way requires a Web browser, preferably Internet Explorer 5.0 or Netscape 4.7 or better. In order to log into JShare, you will need to log into JHED and accept the terms and conditions. If you do not accept the disclaimer, you are waiving your right to access the system.

Visit http://www.it.jhu.edu/jshare/ for more information.

JHSecure – JHSecure is a flexible IPSec based remote access VPN solution, which allows members of the Hopkins communities to access computer resources located at Hopkins from remote locations. More information and download instructions can be accessed through the myJhed tab on the Johns Hopkins portal (https://my.johnshopkins.edu). Note: You must have an active JHEM 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 and/or removed 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 use this web site (http://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.

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.

Students are issued a JCard by the JCard Office upon registering. This card entitles them to use the Eisenhower Library and the Hutzler Reading Room (a 24-hour undergraduate library located in Gilman Hall).

**Bookstore**
Barnes & Noble Johns Hopkins is located at 3300 St. Paul Street (corner of St. Paul and 33rd). Store hours are Monday through Saturday, 9 a.m. to 10 p.m.; and Sunday 10 a.m. to 9 p.m. Textbooks can be ordered online at [http://johns hopkins bkstore.com](http://johns hopkins bkstore.com). Barnes & Noble Johns Hopkins sells new and used textbooks, study aids, school supplies, Johns Hopkins sportswear, and a variety of discount books. Special book order services also are available. For more information, call 410-662-5850.

**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 Jazzman’s Café located in the Levering Lobby, offering gourmet coffee, sandwiches, and pastries. The hours of operation at the food court vary by restaurant and are as follows: Sky Ranch Grill, Pete’s Arena, and Sub Connections are open Monday through Friday, 10:30 a.m.–2:30 p.m.; the Salsa Rico is open Monday through Friday, 10:30 a.m.–8 p.m. The Jazzman’s Café is open Monday through Friday, 7:30 a.m.–4 p.m.

**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 strategically at 14 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 Garland, Clark, and Stony Run 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 case of an emergency, call 410-516-7777.

**Parking**
Parking arrangements are made in Room 7 of Shriver Hall. Parking office hours are Monday through Thursday, 8 a.m. to 7:30 p.m.; Fridays, 8 a.m. to 5 p.m. 410-516-7275.

**Applied Physics Laboratory Education Center**
The mission of the Applied Physics Laboratory (APL), a division of the Johns Hopkins University, includes the application of advanced science and technology to the solution of problems of national and global significance. Although APL is primarily a research and development organization, the Laboratory maintains strong academic relationships with the other divisions of the University.

The APL Education Center is a major site for part-time Hopkins graduate students pursuing technical degrees. Most courses are offered in the Kossiakoff Center, a modern auditorium and classroom building on the APL campus. One wing of the building contains classrooms, well-equipped laboratories and computer facilities, and a vending area.

**Library**
The R.E. Gibson Library maintains an extensive print collection of books and journals for research by the APL professional staff and scholarly community and a reserve collection for student use. While reference and reserve materials are non-circulating, students may check out any of the other holdings by presenting their JCard. Circulating materials from any other Hopkins library may be requested through the library catalog for delivery to the Gibson Library. In addition, a multitude of databases in all disciplines, including IEEE Xplore, Compendex, Inspec, and hundreds more, are accessible both on-site at the Gibson Library and through the JHU proxy server. Subject holdings include physics, aeronautics, electrical engineering, computer science, mathematics, and mechanical and biomedical engineering. During the fall and spring terms when classes are in session, the hours are 8:30 a.m. to 9 p.m., Monday through Thursday, and 8:30 a.m. to 5:30 p.m. on Friday; during the summer session the hours are 8:30 a.m. to 5:30 p.m., Monday through Friday.

Students must present their JCard at the circulation desk to use library resources.

Additional classrooms, laboratories, and the center office are located in the library building.

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

- **Bookstore**
Textbooks for courses at APL may be purchased or exchanged during late afternoon and early evening hours during the start of each term. Textbooks can also be ordered online at [http://johnshopkins.bkstore.com](http://johnshopkins.bkstore.com). Specific hours of the bookstore’s operation at APL are posted at [www.epp.jhu.edu](http://www.epp.jhu.edu).

- **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 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 11 computer labs, a full-service library, café, bookstore and extensive conference space, welcomes 5,000 students per year. Five 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 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., Monday through Thursday; noon to 6 p.m., Friday; and 10:00 a.m. to 5 p.m., Saturday.

- **Computers**
Computer facilities at the Montgomery County Campus 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 the Montgomery County Campus.

- **Bookstore**
Textbooks are available before and during in-person registration and during the first two weeks of classes. Throughout the semester, books, supplies, and other course related materials can be purchased at the bookstore and can also be purchased online at [www.jhutextbooks.com](http://www.jhutextbooks.com). The bookstore has daytime and evening hours to accommodate student and faculty needs.

- **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 upon 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 now houses the admissions and registration staff, and will serve 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, Elkridge, MD.

  The center has an instructional laboratory equipped with Sun 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 center is also the site of the School’s Microwave Engineering Laboratory. This is a state-of-the-art facility for designing, developing, and testing microwave chips and circuits. This laboratory houses a full variety of microwave test 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 student and 1 instructor) offering the latest versions of following software:

  - Pro/Engineer and Pro/a list for mechanical engineering and analysis
  - Agilent ADS, Sonnet, MatLab & gEE-CAD for microwave chip and circuit design and analysis
  - OrCAD 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, 10 colleges and universities are participating and offering programs in education, management, and engineering and applied science. Facilities include two buildings with classrooms, a large multipurpose room, computer labs, a learning conference room, a student lounge, a vending area, and interactive video conferencing capability.

**Washington DC Center**
The Washington Center is a convenient location in the heart of Washington, D.C., Dupont Circle Metro stop. Selected courses in the environmental engineering and science program are currently being offered on site.

**Higher Education and Applied Technology (HEAT) Center**
The HEAT Center is located in Harford County. Selected courses in environmental engineering, science and management and systems engineering are currently being offered.

**Online Courses**
EPP offers some courses and degrees completely online. Available courses are listed in a separate location category under each program in the course schedule for each term. The courses that are available online will increase each term, so students are encouraged to check each term for new offerings.

EPP also offers two fully online degrees. The Master of Science in Bioinformatics degree is offered jointly with the Krieger School of Arts and Sciences (KSAS) Advanced Academics Programs (AAP). All courses may be taken online and there is no residency requirement. See the Bioinformatics program for more information. The Master of Science in Environmental Planning and Management is also offered fully online. See the Environmental Engineering, Science, and Management program for more information.

EPP develops online courses in one of two ways. One method seeks to replicate the traditional classroom experience and relies heavily on streamed video of recorded lectures of face to face classes for content delivery. Homework and assessment are very similar to what would be delivered in a face to face class. These courses are referred to as distance education courses.

The other method seeks to replicate the student learning outcomes from our face to face programs, using best practices in online education. The courses are student centered and designed to foster active and collaborative learning. This method fosters an interactive style of problem solving that improves student comprehension. Content, delivered by many methods and assessments, may be slightly different from that used in the parallel face to face class, but the student learning outcomes are the same. These courses are referred to online courses.

Both distance and online courses follow the normal academic schedule for each term, unless noted in the schedule. They are not self-paced. All registered students proceed through the course as a group, communicating online with their instructor and each other and, where appropriate, working in groups on team projects. The workload in distance and online courses is comparable to that in courses meeting face to face, but is often distributed more evenly throughout the week than is typical for courses taught in the classroom.

The courses are taught completely over the internet and primarily through a course website. Students must have a working email address and reliable and easily accessible internet access in order to complete course work successfully. There may be additional technical requirements for some courses, such as specific software, access to a fax machine, or specific players or plugins. Further information about the requirements for a specific course can be obtained by emailing epponline@jhu.edu or calling 410-516-8758.

**• Registration Deadlines**
Students enrolling in their first EPP online course must be registered a week and a half prior to the first day of classes in order to attend the mandatory online orientation during that week. Returning online students are strongly encouraged to register early. Registration later than a week before the first day of the term may result in delayed access to the course website. Note that these deadlines may preclude registration at some of the new student advisory sessions. 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 courses. See the Academic and Registration Calendar for exact dates for each term.

• **Online Orientation**
Students enrolling in their first EPP online course must attend a mandatory online orientation. See the Academic and Registration Calendar for the exact dates each term. The orientation takes place online during the week prior to the start of the term. Students will be given access to the orientation via email. The time commitment overall is minor, but students are required to log in at least twice, separated by 24 hours, so early participation is recommended. The orientation will identify and address technical access issues, introduce the student to the interface and online tools used to deliver the course, and prepare the student to be a successful online learner. Students are only required to take this orientation the first time they enroll in an online course offered by EPP.

• **Books for Online Courses**
Students will receive a list of required and recommended textbooks via e-mail prior to the first day of classes each term. Textbooks and other course related materials may be purchased online at [http://johns-hopkins.bkstore.com](http://johns-hopkins.bkstore.com).

**Inter-site Links**
To increase the variety of course selection at the centers, select courses are offered using video-conferencing 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, 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 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, the Montgomery County Campus, and the Homewood campus.

Program Committee

James C. Spall, Program Chair
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Applied Physics Laboratory

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Edward R. Scheinerman
Professor, Applied Mathematics and Statistics
Whiting School of Engineering

Jacqueline K. Telford
Principal Professional Staff
Applied Physics Laboratory

J. Miller Whisnant
Principal Professional Staff
Applied Physics Laboratory

Admission Requirements

M.S. Degree or Special Student. Applicants must meet the general requirements for admission to graduate study, outlined in this catalog in the Admission Requirements section. 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, 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.

Course Requirements

M.S. 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, 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 adviser. Two one-term elective courses are also to be taken. These may be from the ACM program or from another graduate program described in the catalog, subject to the approval of the student’s adviser. 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-run interest in pursuing a Ph.D. through the Applied Mathematics and Statistics (AMS) Department at the Homewood campus should coordinate his/her course plan with an ACM adviser and with a representative in the AMS Department. Certain courses within ACM may be especially helpful in passing the required entrance examination for the Ph.D. program. No priority of admission for the Ph.D. 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

- 625.403 Statistical Methods and Data Analysis
- 625.417 Applied Combinatorics and Discrete Mathematics
- 625.420 Mathematical Methods for Signal Processing
- 625.423 Introduction to Operations Research: Probabilistic Models
- 625.438 Neural Networks
- 625.461 Linear Models and Regression
- 625.462 Design and Analysis of Experiments
- 625.480 Cryptography
- 625.490 Computational Complexity and Modern Computing
- 625.495 Time Series Analysis and Dynamic Modeling
- 625.710 Fourier Analysis with Applications to Signal Processing and Differential Equations
- 625.714 Introductory Stochastic Differential Equations with Applications
- 625.721 Probability and Stochastic Process I
- 625.722 Probability and Stochastic Process II
- 625.725 Theory of Statistics I
- 625.726 Theory of Statistics II
- 625.734 Queuing Theory with Applications to Computer Science
- 625.740 Data Mining
- 625.743 Stochastic Optimization and Control
- 625.744 Simulation and Monte Carlo Methods

II. Applied Analysis

- 625.401 Real Analysis
- 625.402 Modern Algebra
- 625.404 Ordinary Differential Equations
- 625.409 Matrix Theory
- 625.411 Computational Methods
- 625.480 Cryptography
- 625.490 Computational Complexity and Modern Computing
- 625.703 Functions of a Complex Variable
- 625.710 Fourier Analysis with Applications to Signal Processing and Differential Equations
- 625.717 Advanced Differential Equations: Partial Differential Equations
- 625.718 Advanced Differential Equations: Nonlinear Differential Equations and Dynamical Systems
- 625.728 Measure-Theoretic Probability
- 605.727 Computational Geometry (elective)
- 613.765 Chaos and Its Applications (elective)

III. Operations Research

- 625.403 Statistical Methods and Data Analysis
- 625.409 Matrix Theory
- 625.414 Linear Optimization
- 625.415 Nonlinear Optimization
- 625.417 Applied Combinatorics and Discrete Mathematics
- 625.423 Introduction to Operations Research: Probabilistic Models
- 625.436 Graph Theory
- 625.439 Mathematics of Finance
- 625.461 Linear Models and Regression
- 625.462 Design and Analysis of Experiments
- 625.495 Time Series Analysis and Dynamic Modeling
- 625.714 Introductory Stochastic Differential Equations with Applications
- 625.721 Probability and Stochastic Process I
- 625.722 Probability and Stochastic Process II
- 625.725 Theory of Statistics I
- 625.726 Theory of Statistics II
- 625.734 Queuing Theory with Applications to Computer Science
- 625.740 Data Mining
- 625.743 Stochastic Optimization and Control
- 625.744 Simulation and Monte Carlo Methods

IV. Information Technology and Computation

- 625.403 Statistical Methods and Data Analysis
- 625.409 Matrix Theory
- 625.411 Computational Methods
- 625.414 Linear Optimization
- 625.415 Nonlinear Optimization
- 625.417 Applied Combinatorics and Discrete Mathematics
- 625.423 Introduction to Operations Research: Probabilistic Models
- 625.436 Graph Theory
- 625.438 Neural Networks
- 625.461 Linear Models and Regression
- 625.480 Cryptography
- 625.490 Computational Complexity and Modern Computing
- 625.495 Time Series Analysis and Dynamic Modeling
- 625.725 Theory of Statistics I
- 625.726 Theory of Statistics II
- 625.734 Queuing Theory with Applications to Computer Science
- 625.740 Data Mining
- 625.743 Stochastic Optimization and Control
- 625.744 Simulation and Monte Carlo Methods
Course Descriptions

Courses numbered 700-level and above are open only to students who have been approved for graduate status. Courses are taught mainly at the Applied Physics Laboratory campus, but some courses are also offered at the Dorsey Center and Montgomery County campuses. For continuity, both semesters of a two-semester course should normally be taken at the same campus. Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

Non-Graduate Credit Courses

The 200-level courses offered are intended to provide mathematical background for graduate course work in EPP. These 200-level courses are not for graduate credit. Some students may find one or more of these courses useful as a refresher or to fill gaps in their training.

- 625.201 General Applied Mathematics
- 625.250 Applied Mathematics I
- 625.251 Applied Mathematics II
- 625.260 Introduction to Linear Systems

Non-Graduate Course Characteristics and Relationships to Each Other

These non-graduate courses have the following characteristics and relationship to each other:

- 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;
- 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; and
- 625.260 on linear systems is designed primarily for students entering the Electrical and Computer Engineering program, but may also be relevant to those in other programs 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).

Prerequisite: Two semesters of calculus.

Note: 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.

C. 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.

Prerequisite: Differential and integral calculus.

Fall D’Archangelo
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.
Prerequisite: Differential and integral calculus. Students with no experience in linear algebra may find it helpful to take 625.250 Applied Mathematics I first.
Spring D’Archangelo

625.260 Introduction to Linear Systems
This course is designed primarily for students who do not have a bachelor’s degree in electrical engineering. It provides prerequisite material needed before entering many of the systems and telecommunications courses offered in the Master of Science in Electrical Engineering program. The course may also be useful to those in other fields with general interests in linear systems analysis. 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.
Prerequisite: Differential and integral calculus.
Effler, Iglesias

Graduate Courses

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.
Prerequisite: Multivariate calculus.
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.
Nakos

625.403 Statistical Methods and Data Analysis
This course introduces commonly used statistical techniques. The intent of this course is to provide an understanding of statistical techniques and a “tool box” of methodologies. Statistical software is used so students can apply statistical methodology to practical problems in the workplace. Intuitive developments and practical use of the techniques are emphasized rather than theorem/proof developments. Topics include the basic laws of probability and descriptive statistics, conditional probability, random variables, expectation, discrete and continuous probability models, joint and sampling distributions, hypothesis testing, point estimation, confidence intervals, contingency tables, logistic regression, and linear and multiple regression.
Prerequisite: Multivariate calculus.

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

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.
Koch, Rio

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 the industries 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++, or other language. Courses in matrix theory or linear algebra, and differential equations would be helpful but are not required.

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.

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

Fall, even years 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 convex analysis, first and second order optimality conditions, Karush-Kuhn-Tucker (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).

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

Fall, odd years Castello

625.417 Applied Combinatorics and Discrete Mathematics

This course is the same as 605.423 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.

Whisnant

625.420 Mathematical Methods for Signal Processing

(formerly Signal Processing and Spectral Analysis)

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, autoregressive-moving average spectral estimates and Burg maximum entropy method.

Prerequisite: 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.

Summer, odd years Boules

625.423 Introduction to Operations Research: Probabilistic Models

This course provides an introduction to some of the more useful OR models that exploit basic concepts and principles of probability and statistics. Although the course is organized around mathematical models and methods, the focus is on practical solutions to real operational problems; sufficient theory is provided to develop understanding of fundamental
results. Topics may vary, being selected from the fields of Markov chains, queueing theory, decision theory, Bayesian networks, reliability and maintenance, activity networks, Markov decision processes, and inventory theory.

**Prerequisites:** Multivariate calculus and a course in probability and statistics (such as 625.403).

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.

**Prerequisite:** Linear algebra.

DeVinney, Fishkind, Scheinerman

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.)

Fall and Spring

Fleischer, Whisnant

625.439 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.

Pemy

625.461 Linear Models and Regression

Introduction to regression and linear models including least squares estimation, maximum likelihood estimation, the Gauss-Markoff Theorem, and the Fundamental Theorem of Least Squares. Topics include estimation, hypothesis testing, simultaneous inference, model diagnostics, transformations, multicollinearity, influence, model building and variable selec-

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.

Staff

625.460 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 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.

Nakos

625.490 Computational Complexity and Modern Computing

This course will cover the basic issues of computational complexity, with a focus on applications that require novel computational methods. We will start with a discussion of
algorithm complexity and NP-completeness. Issues related to complex and high-dimensional data, including the curse of dimensionality, will be studied in some detail. We will also look at novel computing techniques, such as quantum and molecular computing, which may be the computational tools of the future. The lectures will be enhanced through readings and homework.

Prerequisites: A graduate course in probability and statistics such as 625.403. Students should also be familiar with basic linear algebra and have a strong interest in mathematics and computation.

Fleisher

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); familiarity with matrix theory and linear algebra.

Note: This course is also offered in the Department of Applied Mathematics and Statistics (Homewood campus).

Torscaco

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.

Prerequisite: 625.401 Analysis, or 625.404 Ordinary Differential Equations, or permission of the instructor.

Whisnant

625.710 Fourier Analysis with Applications to Signal Processing and Differential Equations

This applied course covers the theory and applications of Fourier analysis, including the Fourier transform, the Fourier series, and the discrete Fourier transform. Applications in signal processing will be emphasized, including the sampling theorem and aliasing, convolution theorems, spectral analysis, and the imaging point spread function. Further applications, also incorporating the Laplace transform, will be taken from studies of differential equations arising in engineering and physics.

Prerequisite: Some familiarity with complex variables, differential equations, and linear algebra.

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. Exposure to ordinary differential equations.

Burkhardt

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 is not sufficient to meet the prerequisites).

Han

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 is not sufficient to meet the prerequisites.)
625.721 Probability and Stochastic Process I

This 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.

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.

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.

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 Cramér-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.

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), the central limit theorem, and martingales.

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

Hill

625.734 Queuing Theory with Applications to Computer Science

This course is the same as 605.725, Queuing Theory with Applications. Queues are a ubiquitous part of everyday life; common examples are supermarket checkout stations, help desks 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.

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

Nickel

625.740 Data Mining

Data mining has become very important in corporate decision making, and is becoming increasingly important in government. With the advent of large data warehouses, organizations have access to huge quantities of potentially valuable data that they would like to mine in order to produce business intelligence. This course provides an advanced introduction to the theory and practice of data mining. The emphasis of the course will be on the following topics: opportunity identification, estimating the value of a data mining solution, process standards for data mining, mathematical problem formulation, complexity control and Vapnik-Chervonenkis theory, optimization algorithms, data and dimensionality reduction techniques, regression methods, and predictive classification. Techniques referenced will include classical statistical approaches, neural networks, decision trees, and local smoothing methods. These concepts will be introduced through lectures, readings, applied problem solving, and a major project. Most of the examples to illustrate these applications will come from banking, insurance, and direct marketing.

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

Staff
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 are discussed.

Prerequisites: Multivariate calculus, matrix 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. It is recommended that this course be taken in the last half of a student’s degree program.

Spall

625.744 Simulation and Monte Carlo Methods
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. As a reflection of the inherent multi-disciplinary nature of simulation, a broad range of topics will be covered: random number generation, model building, bias-variance tradeoff, simulation-based optimization, Markov chain Monte Carlo (MCMC), numerical integration, and input selection using experimental design.

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 in the last half of the student’s degree program.

Spall/I. Wang

625.800 Independent Study in Applied and Computational Mathematics
An individually tailored, supervised project on a subject related to applied and computational mathematics. The independent study project proposal form must be approved prior to registration. A maximum of one independent study course may be applied toward the Master of Science degree or Post-Master’s Certificate.

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 Program in Applied Biomedical Engineering is to educate and train practicing scientists and engineers to be able to carry out engineering-oriented research and development in the biomedical sciences. This program began in 1993.

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 APL campus; however, some electives are offered only at the Homewood campus.

Program Committee
Russell L. McCally, Program Chair
Principal Professional Staff, Applied Physics Laboratory
Associate Professor of Ophthalmology, School of Medicine

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

Eileen Haase
Instructor, Biomedical Engineering, School of Medicine

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

Admission Requirements
Applicants must meet the general requirements for admission to a graduate program outlined in this catalog in the Admission Requirements section. 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, inorganic and organic. 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
A total of 10 one-semester courses must be completed within five years. The curriculum consists of five required courses listed in section II in this program, three to four courses elected from the Applied Biomedical Engineering curriculum listed in section III, and one to two courses elected from other offerings of the School of Engineering with the approval of the student’s adviser. Also, with adviser approval, an elective course may be substituted for a required course if the student has previously completed an equivalent graduate level course or can demonstrate competency. Students may also select electives from the graduate courses in the Biomedical Engineering Department that are listed under section IV in this program with the approval of their adviser and the instructor. These courses are offered either at the Medical School or Homewood campus at their regularly scheduled hours during the day. With approval of their adviser, students may also partially fulfill the elective requirement with related courses offered through the part-time programs of the Krieger School of Arts and Sciences. At least four electives must be for advanced graduate credit, i.e., at the 600-, 700-, or 800-level. Students are required to file a program plan listing the courses they plan to take. The program plan must be approved by the student’s adviser.

I. Non-Credit Courses
585.209 Organic Chemistry
625.201 General Applied Mathematics

II. Required Courses
Five one-semester courses
585.405-406 Physiology for Applied Biomedical Engineering
585.407 Molecular Biology
585.408 Medical Sensors and Devices
585.409 Mathematical Methods for Applied Biomedical Engineering
(625.701-702 Mathematical Methods may be substituted for this course and one elective with permission of the adviser.)

III. Elective Courses
Offered at the Applied Physics Laboratory or the Dorsey Center. The intent is to offer additional electives as the program matures.
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 Orthopaedic Biomechanics
585.624 Neural Prosthetics: Science, Technology, and Applications
Applied Biomedical Engineering

Graduate Programs

585.626 Biomimetics in Biomedical Engineering
585.634 Biophotonics
585.800 Special Project in Applied Biomedical Engineering
585.801 Directed Studies in Applied Biomedical Engineering

IV. Elective Courses
Offered at the Homewood campus. (These may be taken for credit if the prerequisites can be satisfied and with the approval of the instructor.)

580.625-626 Structure and Function of the Auditory and Vestibular Systems
580.628 Modeling the Auditory System
580.632 Ionic Channels in Excitable Membranes
580.634 Molecular and Cellular Systems Physiology Laboratory
580.637 Cellular and Tissue Engineering
580.638 Cell Mechanics and Motility
580.644 Neural Control of Movement and Vocalization
580.651 Introduction to Nonlinear Dynamics in Physiology
580.673 Advanced Seminar in Magnetic Resonance Imaging
580.683 High Performance Computing in Biology
580.684 Experimental Foundations for Neural Models
580.702 Neuroengineering

Course Descriptions

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

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 Master of Science in Applied Biomedical Engineering degree.)

Prerequisite: 585.209 Organic Chemistry.

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.

Prerequisite: 585.209 Organic Chemistry. Two-term course.

Haase, Berman

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.

Prerequisite: 585.209 Organic Chemistry.

Kistenmacher, 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 first discussed. 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 the students will obtain hands-on experience with electronic components, sensors, biopotential measurements and testing of therapeutic instrumentation.

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.

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### 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.

**Prerequisite:** 585.409 Mathematical Methods for Applied Biomedical Engineering.

Kistenmacher, Staff

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### 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.

**Prerequisite:** Familiarity with linear algebra and Fourier transforms.

Bankman, Pham, Spisz

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### 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. The new course, Medical Imaging II, provides more information on the physics, imaging procedures, and advanced techniques of MRI. The new course also includes two lectures on nuclear medicine.

**Prerequisite:** 585.409 Mathematical Methods for Applied Biomedical Engineering or equivalent.

Spencer

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### 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 solgel 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.

**Prerequisite:** 585.209 Organic Chemistry.

Potember

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### 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. The classes also include students’ presentations of original journal papers, covering additional topics and stimulating their preparation and involvement in the class.

Spector

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### 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.

Bryden, Potember

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### 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.

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); topics in biomedical optics (e.g., microscopy, optical coherence tomography); neurophysiology (mechanisms of pain perception); neural signal processing; medical image processing; and MRI. Topics will be presented by instructors who are actively engaged in researchail in the various areas.

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.

Spector

585.620 Orthopedic Biomechanics

This course is an introduction to the field of orthopedic biomechanics for the engineer. The course will cover the structure and function of the musculoskeletal system, including detailed discussions on the material properties of bone, ligament, tendon, cartilage, and muscle. Other topics of discussion will include viscoelasticity, bone remodeling, and injury mechanisms. Journal articles from the biomechanics literature will be used to explore current areas of active research.

Prerequisite: Statics required and dynamics recommended.

Kleinberger

585.624 Neural Prosthetics: Science, Technology, and Applications

This course will address 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.

Harshbarger, Staff

585.626 Biomimetics in Biomedical Engineering

Biomimetic refers to human-made processes, substances, devices or systems that imitate nature. This course focuses on substances prepared and engineered to meet biomedical uses. The course is designed to provide students with: (a) an understanding of the biomimetic process of self-assembly; (b) an introduction to bioengineering biological materials and novel biomimetic materials that include forms and structures useful to bioprocesses; (c) 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.

Murray, Van Houten

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 as well as 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.

Sova, Ramella-Roman

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 of interest. The research problem can be addressed experimentally or analytically. A written report is produced on which the grade is based. This course is open only to graduate candidates in the Master of Science in Applied Biomedical Engineering program. The applied biomedical engineering project proposal form must be completed prior to registration.

Prerequisite: Permission of the instructor.

Staff

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. This course is open only to graduate candidates in the Master of Science in Applied Biomedical Engineering program. The
applied biomedical engineering directed studies program proposal form must be completed prior to registration.

Prerequisite: Permission of the instructor.

580.625-626 Structure and Function of the Auditory and Vestibular Systems
(formerly Structure and Function of the Auditory System)
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.

Prerequisite: 580.421-422 Physiological Foundations for Biomedical Engineering or equivalent. Recommended: 110.302 Differential Equations, 520.214 Signals and Systems.

Fall (even years), Spring (odd years)
Hearing Science Center Staff

580.626 Modeling the Auditory System
The physiology of hearing from a model-oriented viewpoint; intended as a complement to 580.625-626. Topics include basilar membrane mechanics, models of cochlear transduction, stochastic process models of neural discharge, detection theoretic approaches to relating physiological and psychological data, models of signal processing in central auditory nuclei, and nonlinear methods of characterizing neurons.

Prerequisites: 580.421-422 Physiological Foundations for Biomedical Engineering, or equivalent, 110.302 Differential Equations or 500.303 Applied Mathematics I or equivalent. Recommended: 520.214 Signals and Systems.
Spring (even years)
Sachs, Young

580.630 Theoretical Neuroscience
Theoretical methods for analyzing information encoding and representing function in neural systems. 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; network models of neural systems. Both theoretical methods and the properties of specific well-studied neural systems will be discussed.

Prerequisites: Introduction to Neuroscience (580.422 or equivalent), Probability (550.420 or equivalent), and Signals and Systems (520.214).

Spring 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.

Prerequisite: 580.421-422 Physiological Foundations for Biomedical Engineering or equivalent introductory biology. Recommended: differential equations, linear algebra, signals, and elementary probability.

Fall (even years)
Yue

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

Spring (odd years)
Tung, Yue

580.637 Cellular and Tissue Engineering
This is an advanced course on the latest research accomplishments on cellular and tissue engineering from three different interdisciplinary perspectives: (a) It summarizes the theoretical/experimental tools to investigate adhesion mechanisms and differentiated functions of cells attached on surfaces. (b) It examines the signal transduction and regulation of metabolic activity in mammalian cells due to physical (mechanical) forces. (c) It highlights the mechanisms of cell motility and morphogenesis of anchored cells, and the mechanical properties of circulating cells.

Fall (even years)
Alevriadou, Leong, Kuo, Popel

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 interdisci-
A comprehensive approach spanning molecular biology, biochemistry, physics, and engineering will be emphasized.

**Prerequisite:** 580.421 Physiological Foundations for Biomedical Engineering or 020.305-306 Biochemistry and Cell Biology

**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.

**Prerequisite:** A previous course in neuroscience.

**Fall**

Shadmehr, Wang

**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, nonlinear forecasting. Examples will be drawn from studies in cardiology, brain function, and the oculomotor system.

**Prerequisite:** Basic knowledge of signals and systems or permission of instructor. Limited enrollment.

**Fall (even years)**

Shelhamer

**580.673 Advanced Seminar in Magnetic Resonance Imaging**

In this course, students present an idea from the current literature to the class in two two-hour seminars and write a 10–20 page review article on the same topic. At the end of the course the class produces a book of these articles. Recent topics: rf and gradient coil design, flow measurements with MRI and contrast injection, sub-second MRI, methods for designing rf pulse shapes, diffusion measurements with MRI, absolute quantification of metabolites with MRS, cardiac MRI. Future topics: adiabatic pulses in MRI and spectroscopy, motion artifact reduction, reconstruction strategies in reduced k-space MRI, thermal and mechanical requirements for MRI hardware, patient safety, induced currents from rapidly switching gradients, rf heating.

**Prerequisites:** 580.472-473 Medical Imaging Systems and Magnetic Resonance in Medicine.

**Spring (odd years)**

McVeigh

**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 (a) review of high performance computing in molecular modeling, biological fluid dynamics and transport, and cell network modeling; (b) efficient numerical methods for use on high performance computing systems; and (c) 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, differential equations, and linear algebra.

**Spring**

Winslow, Jafri

**580.684 Experimental Foundations for Neural Models**

This course familiarizes students with the experimental tools that are used to provide the biological database 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:** An introductory course on the nervous system and permission of instructor.

**Spring**

Sachs, Staff

**580.702 Neuroengineering**

Neuroengineering represents the application of engineering principles to develop systems for neurological research and clinical applications. This involves design of instrumentation for brain monitoring, development of signal processing methods to analyze brain rhythms, contemporary imaging methods ranging from optical/CT/MRI, use of micro and nanotechnologies to probe from neurons and brain, and development and application of neural stimulators, prostheses, deep brain stimulations, and robotic/image guided therapeutic devices. The course will review and research the state of the art in selected fields and support research and development projects by students in these topics.
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 the 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, 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 this catalog in the Admissions Requirements section. 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 courses 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 adviser.

Four of the 10 courses required for the degree must be at the 700- or 800-level. With the adviser'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:

- 615.441 Mathematical Methods for Physics and Engineering
- 615.442 Electromagnetics
- 615.451 Statistical Mechanics and Thermodynamics
- 615.453 Classical Mechanics
- 615.454 Quantum Mechanics
- 615.465 Modern Physics
- 615.471 Principles of Optics
- 615.480 Materials Science
- 615.491 Physical System Modeling
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**
- 615.472 Optical Remote Sensing
- 615.751 Modern Optics
- 615.752 Statistical 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**
- 615.460 Sensors and Sensor Systems for Homeland Security
- 615.746 Nanoelectronics: Physics and Devices
- 615.747 Sensors and Sensor Systems
- 615.757 Solid State Physics
- 615.760 Physics of Semiconductor Devices
- 615.768 Superlattices and Heterostructure Devices

**Additional**
- 615.448 Alternate Energy Technology
- 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

615.441 Mathematical Methods for Physics and Engineering
615.442 Electromagnetics
615.454 Quantum Mechanics

Applied physics offers eight additional optics courses. Of the remaining seven courses, five or more must be photonics courses selected from both the applied physics and electrical engineering curricula.
- 615.471 Principles of Optics
- 615.472 Optical Remote Sensing
- 615.751 Modern Optics
- 615.752 Statistical 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.

Electrical 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
- 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 Option**

Students can elect to concentrate their studies in Materials and Condensed Matter by completing a combination of courses from the Applied Physics, Electrical Engineering, and the 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 Engineering, Materials Science and Engineering, and Chemical Engineering curricula.
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.

615.441 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).
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.
Thompson, Najmi

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.)
Prerequisite: An undergraduate degree in physics or engineering or the equivalent.
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.)
Prerequisite: 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.
Staff

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.

**Prerequisite:** An undergraduate degree in engineering, physics, or a related technical discipline.

**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.

**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.

**Prerequisite:** Intermediate mechanics and 615.441 Mathematical Methods for Physics and Engineering.

**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.

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

**Najmi**

**615.460 Sensors and Sensor Systems for Homeland Security**

This course will present an overview of sensors and methods to protect populations against weapons of mass destruction. Using threat scenarios, the course will review common threat agents and methods of dissemination, and assess their effects on infrastructure. Next, 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. 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 be required to select a sensor suite, and networking information to design a hypothetical system considering the threat, sensor deployment cost and logistics.

**Lesho, Carlson**

**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.

**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.

**Prerequisite:** Undergraduate degree in physics or engineering.

**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
Graduate Programs

Applied Physics

615.472 Optical Remote Sensing
Remote sensing can be described as the collection of information about an object without direct physical contact with the object. Optical systems are playing an increasingly more important role in remote sensing. The first part of this course will describe the nature of light, its propagation through mediums, and the optical systems that are designed to collect or image the light. Consideration will be given to optical system radiometry in both the visible and infrared bands. The second part of the course considers specific systems designed for particular applications, both image-based and signal-based, including FTIR and LIDAR systems. Access to Matlab, Mathematica or MathCAD is required to complete some of the assignments.

Prerequisites: An undergraduate degree in engineering or physics or equivalent with a basic understanding of optics and electromagnetics at the undergraduate level.

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.

Prerequisite: Undergraduate degree in physics or engineering.

615.481 Polymeric Materials
A comprehensive course in polymeric materials. Topics to 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.

615.491 Physical System Modeling
This course provides an introduction to the modeling of physical systems. Each field will be introduced in the context of general principle illustrated by the solution of representative problems. Topics to include fluids (viscous, inviscid, compressible and incompressible), linear and nonlinear elasticity, heat conduction, deformable media, strain, plasticity, electromagnetism, etc.

Prerequisites: 615.441 Mathematical Methods for Physics and Engineering and a basic understanding of physics and mechanics.

615.492 Systems Engineering Science
This course is designed to reinforce the scientific and engineering foundations of the engineering design, development, testing, and deployment of complex systems. The subject ranges from project planning through key analytic and physical principles of reliability, economics, decision theory, and optimization. Important fundamental aspects of electrical, mechanical and system packaging are presented along with their defining equations and approximations. Quality of both hardware and software is discussed along with the various aspects of technology transfer and the transition from prototype development to fielded systems.

Prerequisite: An undergraduate degree in physics or engineering or the equivalent with a basic understanding of engineering mathematics. 615.441 Mathematical Methods for Physics and Engineering is recommended but not required.

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.)

Prerequisite: An undergraduate degree in physics or engineering or the equivalent.

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.)

Prerequisite: 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.

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 (see http://www.sematech.org). 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; 615.740 Physics of Semiconductor Devices or equivalent.

Staff

615.747 Sensors and Sensor Systems
The primary objective of this course is to present recent advancements 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.

Bannerjee

615.748 Introduction to Relativity
(formerly 615.772)
Introduction to General Relativity and Cosmology) After a brief review of the Special Theory of Relativity, the mathematical tools of tensor calculus that are necessary for understanding the General Theory of 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.

Najmi

615.751 Modern Optics
This course covers the fundamental principles of modern physical optics 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.

Prerequisite: 615.442 Electromagnetics or the equivalent completed or taken concurrently.

Boone

615.752 Statistical Optics
This is an advanced course in which we explore the field of Statistical Optics. Topics covered include such subjects as the statistical properties of natural (thermal) and laser light, spatial and temporal coherence, effects of partial coherence on optical imaging instruments, effects on imaging due to randomly in homogeneous media, and a statistical treatment of the detection of light. Development of this more comprehensive model of the behavior of light draws upon the use of tools traditionally available to the applied scientist, such as linear system theory and the theory of stochastic processes.

Prerequisite: 525.414 Probability and Stochastic Processes or equivalent.

Staff

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, magneto hydrodynamics, equilibria, waves, instabilities, applications to fusion devices, ionospheric, and space physics.

Prerequisite: 615.442 Electromagnetics or the equivalent.

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 which 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 hyper-velocity 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.

Prerequisite: 615.442 Electromagnetics or the equivalent.

Anderson

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.

**Prerequisite:** 615.454 Quantum Mechanics or the equivalent.

**Ancona**

**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.

**Prerequisite:** 615.454 Quantum Mechanics or the equivalent.  
**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.  
**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 radar 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 cellular 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.  
**Awadallah**

**615.765 Chaos and Its Applications**

This course provides a topical introduction to the basic concepts and active areas of modern nonlinear dynamics, including sensitive dependence on initial conditions, fractals, routes to chaos, experimental techniques, symbolic dynamics, and control of chaos in real systems. The course emphasizes applications to and examples from physics and engineering, including geophysical systems, electronic oscillators, mechanical engineering, and information science. Although some mathematical theory is necessary to develop the material, extensive use of concrete examples helps to develop necessary intuition. 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.

**Prerequisite:** Mathematics through ordinary differential equations. Familiarity with classical mechanics helpful. Consult instructor for more information.  
**Staff**

**615.768 Superlattices and Heterostructure Devices**

In this course, students are introduced to the physics and technology of superlattices and heterostructure devices (i.e., semiconductor devices whose chemical composition is varied in order to optimize electronic and/or optical performance—"band-gap engineering"). Among the devices covered in the course are modulation-doped FETs, hetero junction bipolar transistors and various quantum well devices, such as heterostructure light sources and detectors. Topics include energy band diagrams, electronic properties of heterojunctions, inter-valley and real-space transfer, electron states in quantum wells, excitons, tunneling and transport theory. Student projects involving the use of commercial device simulation software will allow direct exploration of various devices as well as provide experience with a widely used design tool.

**Prerequisites:** 615.454 Quantum Mechanics or the equivalent. Exposure to material covered in 615.760 Physics of Semiconductor Devices and 615.757 Solid State Physics or their equivalent is desirable but not required. No computer experience is necessary.  
**Ancona**

**615.769 Physics of Remote Sensing**

This course exposes the student to the physical principles underlying satellite observations of the Earth by optical, infrared, and microwave sensors, and 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 the Earth's atmosphere, radiative transfer and atmospheric effects, and overviews of some impor-
tant 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.

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), and 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.

Prerequisite: 615.748 Introduction to Relativity.

Najmi

615.773 Coastal Oceanography I
Most of the population of earth lives within 100km of the coasts. The effects of man on that environment are immense. In this course we will study the dynamics, modeling, and predictions of the processes in littoral waters. The coastal water dynamics pose new challenges to the oceanographer than those in the deepwater. In the coastal waters the currents can change on time scales of minutes and over spatial scales of meters. There are huge episodic events such as storm surge, water run off, fresh water plumes, and phytoplankton blooms. In this course we will develop the controlling equations and delineate the multiscale, multidisciplinary nature of coastal processes.

Prerequisites: Differential Calculus and Physics.

Porter, Gasparovic, Staff

615.774 Coastal Oceanography II
This course is a continuation of Coastal Oceanography I. We will use the delineated processes from Coastal Oceanography I and investigate how those processes are being monitored. We will discuss the observation systems ranging from coastal tide gages to the space observing hyperspectral color sensors and synthetic aperture radar systems. We will study the use of models in coastal waters ranging from tracking of airplane debris, to crab larvae, to sewage effluents. The course will conclude with a discussion of commerce, fisheries, naval applications, and management.

Prerequisites: Differential Calculus and Physics.

Gasparovic, Porter, Staff

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.

Winstead and Porter

615.777 Applied Optics
Students acquire a working knowledge of applied optics, enabling them to solve optical design problems and to understand the principles of optical instruments that they will encounter in their professional work. Topics include geometrical optics, ray-trace analysis, optical instruments, spectrometry, radiometry, calibration techniques, detectors, and additional topics (such as atmospheric optics) needed to support other courses in the applied physics curriculum.

Prerequisite: Mathematics through vectors and differential equations.

615.778 Computer Optical Design
In this course students learn to use optical ray-trace analysis to design and analyze optical systems. Students use a full-function optical ray-trace program on personal computers to analyze designs beginning with simple lenses for familiarization with the software, to more complicated wide-angle and zoom lenses, and finally to three-dimensional systems such as spectrographs. 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. Assignments require the use of a Pentium PC running Windows with 16Mb of RAM, and 12Mb of free hard disk space.

Prerequisite: 615.471 Principles of Optics.

Rogala

615.779 Computational Physics
Computer modeling and simulation are becoming increasingly important in applied physics and engineering, with engineers and researchers typically using preexisting, highly sophisticated, graphically oriented software to solve their real-world problems. To succeed in this environment one need not be able to write such state-of-the-art software, but it is vital that one be a smart consumer. With this in mind, this course provides the student with a firm grounding in the fundamentals of numerical applied physics/engineering. Through an interesting mix of principles, practical algorithms, and hands-on computational experience, the student learns the basic concepts that underlie the practical simulation software used in everything from weather prediction to electronic device design. Both ordinary and partial differential equations are discussed, and the topics include convergence, stability, numerical error, ill-conditioning, gridding, finite-differences,
iterative techniques, and stochastic methods. The text for the course was written by the instructor and is printed and sold by the bookstore at cost. This text also exists in an experimental interactive form (Mathcad) which is not required for the course but which will be provided for free to interested students.

**Prerequisites:** Familiarity with differential equations is required and prior exposure to computer programming is recommended.

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**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 photo-emission and photo-excitation follow, including background physics, noise, and sensitivity. Practical devices and practical operational 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.

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

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**615.781 Quantum Information Processing**

This course provides an introduction to the rapidly developing field of quantum information processing. In addition to studying fundamental concepts such as two-state systems, measurements uncertainty, quantum entanglement, and non-locality, emphasis will be placed on 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.

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**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 which 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.

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**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 adviser) must be approved prior to registration.

**Note:** Only open to candidates in the Master of Science in Applied Physics program.

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**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.

**Prerequisite:** The Directed Studies Program Proposal Form (available from the student’s adviser) must be completed and approved prior to registration.

**Note:** Open only to candidates in the Master of Science in Applied Physics program.
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, pathways, and 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, the Whiting School of Engineering, Engineering and Applied Science Programs for Professionals 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. It consists of:

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

Ralph Semmel, Co-chair
Computer Science Program, Whiting School of Engineering, Engineering and Applied Science Programs for Professionals

Edwin Addison, EPP Coordinator
Computer Science Program, Whiting School of Engineering, Engineering and Applied Science Programs for Professionals

Admissions Requirement
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; and Calculus. All the prerequisites can be taken in the existing Master of Science in Computer Science or in 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 may be admitted as provisional students. Applicants with a degree from a country other than the US must provide credential evaluations and a TOEFL.

Note: 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 must be submitted directly to KSAS (http://www.bioinformatics.jhu.edu/).

Program Structure
The joint MS degree will require certain prerequisites and a total of 11 courses. 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
605.421 Foundations of Algorithms
Bioinformatics

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

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

Concentration Courses—Choose Four
Students may choose any four of these courses. If a student chooses three courses in one concentration area, the student will also be recognized as having completed a “concentration” in that specific area. Concentrating on one area is not required.

Protein Bioinformatics
- 410.639 Protein Bioinformatics
- 410.661 Methods in Proteomics
- 605.751 Computational Aspects of Molecular Structure
- 605.759 Independent Project in Bioinformatics

Note: Students may take both 410.639 and 605.751 as the content is sufficiently different.

Genomics and Sequencing
- 410.635 Bioinformatics: Tools for Genome Analysis
- 410.640 Phylogenetics and Comparative Genomics
- 410.666 Genomic Sequencing and Analysis
- 410.671 Microarrays and Analysis
- 410.754 Comparative Microbial Genomics: From Sequence to Significance
- 605.753 Computational Genomics
- 605.754 Analysis of Gene Expression
- 605.759 Independent Project in Bioinformatics

Computational Biology
- 410.640 Phylogenetics and Comparative Genomics
- 410.698 Bioperl
- 410.712 Advanced Practical Computer Concepts for Bioinformatics
- 605.451 Principles of Computational Biology
- 605.456 Computational Drug Discovery and Development
- 605.743 The Semantic Web
- 605.759 Independent Project in Bioinformatics

Systems Biology
- 410.671 Microarrays and Analysis
- 605.456 Computational Drug Discovery and Development
- 605.716 Modeling and Simulation of Complex Systems
- 605.754 Analysis of Gene Expression
- 605.755 Systems Biology
- 605.759 Independent Project in Bioinformatics

Note: 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 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
- 410.800 Independent Research in Biotechnology

Approved Computer Science Elective List
- 605.401 Foundations of Software Engineering
- 605.444 XML: Technology and Applications
- 605.481 Distributed Development on the World Wide Web
- 605.484 Collaborative Development with Ruby on Rails
- 605.706 Software Systems Engineering
- 605.741 Distributed Database Systems
- 605.746 Machine Learning
- 605.747 Evolutionary Computation
- 605.782 Web Application Development with Servlets and JavaServer Pages (JSP)
- 605.787 Rich Internet Applications with Ajax

Online Options
Effective Fall 2006, the Master of Science in Bioinformatics is available as a fully online degree. Not all courses are available online, but a complete program is offered. All bioinformatics students may take advantage of the online offerings as it suits their needs.

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

**Tuition**

Tuition for the courses in the joint degree vary by course and school of origin and are posted in the course schedule each semester.

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**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.

*Prerequisite:* Two semesters of college chemistry.

*Note:* This course does not count toward requirements for the master’s degree in biotechnology.

**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 methodological 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.

**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.

*Prerequisite:* 410.601 Biochemistry.

**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 the experimental techniques used in cell biology to study cell growth, manipulation, and evaluation.

**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.

**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.

**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 disor-
Graduate Programs

Bioinformatics

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.

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 biotechnology, and particularly genomics, will have on the development of antibiotics and vaccines as treatment and preventive measures.

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.

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.

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.

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.

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.

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 interpretation is 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
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.

**Staff**

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.

**Staff**

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.

**Staff**

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-dimensional (3-D) folds and predicting 3-D structures by homology. Computer laboratories complement material presented in lectures.

**Staff**

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 and 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.

**Staff**

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 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.

**Staff**

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

**Staff**
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.

Staff

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 (2-D gel electrophoresis), spectroscopic methods (UV/Vis, Fluorescence, CD), analytical ultra-centrifugation, micro-arrays, mass spectroscopy, amino acid analysis, sequencing, and methods to measure protein-protein interactions.

Staff

410.666 Genomic Sequencing and Analysis
The completion of the human genome sequence is just the latest achievement in genome sequencing. Armed with the complete genome sequence, scientists need to identify the genes encoded within, to assign functions to the genes, and to put these into functional and metabolic pathways. This course will provide an overview of the laboratory and computational techniques beginning with genome sequencing and annotation, extending into bioinformatics analysis and comparative genomics and including functional genomics.

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 multivariate expression data. Additionally, students will visualize the results in modern statistical scripting software. Topics include detecting and attributing sources of data variability, determining differentially expressed genes with relevant statistical tests and controlling for false positive discovery (multiple test corrections, permutations, etc.). An introduction to linear and non-linear dimension reduction methods (PCA, PLS, Isometric feature mapping, etc.) and an introduction to common pattern recognition (clustering), classification, and discrimination techniques will be included. Assignments and concepts will make use of publicly available Affymetrix and cDNA microarray data sets. Examples will mostly be demonstrated in S-plus and R (publicly available) code, with some in SAS. Free demo software tools such as Minitab, Spotfire, TreeView, Expression Profiler, and web UIs will also be utilized.

Staff

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.

Staff

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 a review of 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 upon, 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, as well as 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 project. Once again, whenever possible, this course will emphasize relevance to solving problems in molecular biology and bioinformatics.

Prerequisites: 410.601 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.

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 we 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: 410.601 Biochemistry; 410.602 Molecular Biology; 410.633 Computers in Molecular Biology.

Staff

410.800 Independent Research in Biotechnology Consult with KSAS coordinator for specifics.

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.

Prerequisite: One year of college mathematics.

Note: This course DOES NOT count toward the Master of Science in Computer Science degree.

Chittargi, Ferguson, 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 trade-offs associated with implementing alternative data structures for these ADTs. There will be four or five substantial Java programming assignments.

Prerequisite: One year of college mathematics. 605.201 Introduction to Programming using Java or equivalent.

Note: This course DOES NOT count toward the Master of Science in Computer Science degree.

Chlan, Resch, Tjaden

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.

Chavis, Gieszl, Schappelle, Yufik

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, 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.

Prerequisite: 605.202 Data Structures or equivalent.

Boon, Chlan, Lew, Sadowsky, Sheppard

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.

Immer, Kung, Liu, Semmel
Bioinformatics

605.444 XML: Technology and Applications
This course covers the concepts, technology, and applications of XML (Extensible Markup Language), especially to Web-based technologies. The course concentrates on XML fundamentals and associated technologies, and processing XML using Java. Topics covered include the XML Specification; XML Namespaces; Document Type Definitions (DTDs); XML Schemas; XML Transformation (XSLT); XML Links and XML Pointers; and parsing XML using the Document Object Model (DOM) and Simple API (Application Programming Interface) for XML (SAX), the Java API for XML Processing (JAXP), and the Java Document Object Model (JDOM). Additional topics may be drawn from Cascading Style Sheets (CSS); XQuery; the Simple Object-Oriented Protocol (SOAP); Web Services Description Language (WSDL); Universal Description, Discovery and Integration (UDDI); applications of XML such as RDF; and the architecture of the Web Service, EAI, and B2B systems using XML. (This course is the same as 635.444 XML: Technology and Applications.)
Prerequisite: 605.481 Distributed Development on the World Wide Web or equivalent Java experience.

Chittargi, Silberberg

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; a course in molecular biology and a course in cell biology or biochemistry are highly recommended.

Przytycka

605.452 Biological Databases and Database Tools
The sequencing of the human genome and the emerging intense interest in proteomics and molecular structure have caused an enormous explosion in the need for biological databases. The first half of this course surveys a wide range of biological databases and their access tools and seeks to develop proficiency in their use. These include genome and sequence databases such as GenBank and Ensemble, as well as protein databases such as PDB and SWISSPROT, and their analysis tools. Tools for accessing and manipulating sequence databases will be covered, such as BLAST, multiple alignment, Perl, and gene finding tools. Advanced, specialized and recent popular databases such as KEGG, BioCyc, HapMap, Allen Brain Atlas, Afcs, etc. will be surveyed for their design and use. The second half of this course focuses on the design of biological databases including the computational methods to create the underlying data, as well as the special requirements of biological databases such as interoperability, complex data structures consisting of very long strings, object orientation, efficient interaction with computational operators, parallel and distributed storage, secure transactions and fast recall. Students will create their own small database as a project for the course as well as complete homework assignments using databases.
Prerequisites: 605.441 Principles of Database Systems or 410.634 or working knowledge of SQL, and a prior course in molecular biology or cell biology (605.205 or 410.602).
Note: Students who do not have a prior background in databases can succeed in this course by concurrent self-study of relational databases and SQL using a book such as Database Solutions: A Step by Step Guide to Building Databases, by Thomas Hobbs.

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 translation 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.

Kumar

605.481 Distributed Development on the World Wide Web
This course examines three major topics in the development of applications for the World Wide Web. The first is web site 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).

Evans, Naber, Shyamsunder, Spiegel

605.484 Collaborative Development with Ruby on Rails

Modern web applications are expected to facilitate collaboration, with user participation being a significant aspect of the system. Components such as wikis, blogs, and forums are now commonplace. While feature sets continue to expand, there is a 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.

Prerequisite: 605.481 Distributed Development on the WWW or equivalent.

Weimer

605.706 Software Systems Engineering

(formerly 605.706 The Software Development Process)

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.

Prerequisite: One software engineering course beyond 605.401 Foundations of Software Engineering.

Siegel and Donaldson, White

605.716 Modeling and Simulation of Complex Systems

(formerly 605.752 Simulation of Biological and 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.

This course may be counted toward a three course concentration in Bioinformatics.

Addison

605.741 Distributed Database Systems

This course investigates principles of distributed database systems, including design and architecture, query processing, transaction management, locking, recovery, and RAID technology. The course also covers JDBC programming through a variety of interfaces including stand-alone Java programs, Java applets on web browsers, and Common Gateway Interface programs on web browsers. The course blends theory with practice, and students will use distributed database concepts to develop JDBC applications and JDBC drivers for implementing web-based distributed databases.

Prerequisites: 605.441 Principles of Database Systems, and 605.481 Distributed Development on the World Wide Web or equivalent knowledge of Java and HTML.

Silberberg

605.743 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 throughout the course, including the life sciences, knowledge management, electronic commerce and
Bioinformatics

Graduate Programs

web services choreography. Domain-specific implementation strategies such as LSID (Life Sciences Identifier) and various vertical ontologies will be addressed.

Prerequisite: 605.444 XML: Technology and Applications or equivalent.

Addison

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.

Prerequisite: 605.445 Artificial Intelligence is recommended, but not required.

Sheppard

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.

Prerequisite: 605.445 Artificial Intelligence is recommended, but not required.

Sheppard

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, 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: A course in molecular biology and a course in cell biology or biochemistry are highly recommended.

Panchenko and Przytycka

605.753 Computational Genomics

This course focuses on current problems of computational genomics. Students will use bioinformatics software and learn the principles underlying a variety of bioinformatics algorithms. In addition, students will explore and discuss bioinformatics research, and develop software tools to solve bioinformatics problems. Topics include analyzing eukaryotic, bacterial, and viral genes and genomes; finding genes in genomes and identifying their biological functions; predicting regulatory sites; assessing gene and genome evolution; and analyzing gene expression data.

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

Ermolaeva

605.754 Analysis of Gene Expression

The rapid popularization of microarray technology has led to an explosion in the collection of gene expression data. After a brief survey of existing gene expression software tools, this course emphasizes the development of original algorithms and data mining techniques for analyzing gene expression data. This course covers statistical and analytical methods and software development for the analysis of gene expression data. Topics include (1) a brief survey of existing software for microarray analysis (normalization, differential expression, and clustering); 2) algorithms, database design and data mining techniques for gene expression data; and 3) detailed coverage of analysis and reverse engineering of gene regulatory networks, including relevance networks, Boolean networks and continuous networks. Both static data and time series data will be considered. The student will develop sufficient expertise in both the underlying analysis and statistical theory to develop new algorithms and software to analyze gene expression data. Students will complete several software assignments including the design of a new algorithm for gene expression analysis.

Prerequisites: 605.205 or a course in molecular biology or cell biology, and a course in probability and statistics. Working knowledge of C or JAVA. JHU Online Orientation 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.

Addison
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 datasets 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. As a course project, students will develop a model of a signal transduction or metabolism pathway.

Prerequisites: Courses in molecular biology (605.205 or 410.602) and differential equations.

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 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.

Staff

605.782  Web Application Development with Servlets and JavaServer Pages (JSP)
This project-oriented course investigates techniques for building server-side programs for dynamically generated Web sites, electronic commerce, Web-enabled enterprise computing, and other applications that require WWW access to server-based resources. Particular attention will be paid to methods for making server-side applications efficient, maintainable, and flexible. Topics include handling HTTP request information, generating HTTP response data, processing cookies, tracking sessions, designing custom JSP tag libraries, and separating content from presentation through use of JavaBeans components and the MVC (Model 2) architecture.

Prerequisite: 605.481 or equivalent Java experience.

Chittargi, Hall

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.

Prerequisite: 605.782 or equivalent servlet and JSP experience.

Hall
Chemical and Biomolecular Engineering

In the past decade, the scope of chemical and biomolecular engineering has expanded dramatically. While chemical engineers continue to work in the chemical and petroleum industries, they are just as likely to be employed in biotechnology or pharmaceutical companies, at electronics manufacturing facilities, or in 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 four defined areas: Cell and Molecular Biotechnology, Nano/Microtechnology, Biomaterials/Drug Delivery, 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

Konstantinos Konstantopoulos, Program Chair
Associate Professor of Chemical and Biomolecular Engineering

Kathleen Stebe
Professor of Chemical & Biomolecular 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

Students must complete a program plan and submit it to the program chair for approval upon entering the program. The students who choose to pursue a Masters of Chemical and Biomolecular Engineering with concentration in one of the four defined areas must select courses that do not overlap significantly in technical content with those courses that are part of the core curriculum. Faculty advisers will assist students in making this determination. As one of the program electives, students may complete a faculty-supervised Independent Project, involving in-depth study or critical review of a chemical engineering subject area. Candidates must complete the required course work within five years of admission.

Core Courses

There are four required core courses:

- 540.602 Cellular and Molecular Biotechnology of Mammalian Systems
- 540.630 Thermodynamics and Statistical Mechanics for Chemical and Biomolecular Systems
- 540.644 Interfacial Phenomena in Nanostructured Materials
- 540.652 Fundamentals of Biotransport Phenomena

The student selects additional engineering or science courses with the help of the graduate adviser to design a curriculum appropriate for the student's engineering interest.

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 adviser. These include the four core courses listed above plus six additional courses (for which prerequisites have been met)—three to six selected from the Whiting School's Engineering Programs for Professionals (EPP) and no more than two courses selected from the Krieger School of Arts and Sciences Advanced Academic Program in Biotechnology (courses listed under Group III).

Requirements for Master of C.B.E. with a Concentration in Cell and Molecular Biotechnology

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. As a result, we have developed a program which 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 a student must complete the core courses listed above plus six additional electives which may include:

- 540.602 Cellular and Molecular Biotechnology of Mammalian Systems
- 540.630 Thermodynamics and Statistical Mechanics for Chemical and Biomolecular Systems
- 540.644 Interfacial Phenomena in Nanostructured Materials
- 540.652 Fundamentals of Biotransport Phenomena
- Additional electives from Whiting School's Engineering Programs for Professionals (EPP) and/or Krieger School of Arts and Sciences Advanced Academic Program in Biotechnology (courses listed under Group III).
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540.626 Introduction of Biomacromolecules
540.633 Engineering Aspects of Controlled Drug Delivery
540.642 Advanced Topics in Biochemical Kinetic Processes
540.660 Computational and Experimental Design of Biomolecules

Additionally, students may complete two to three courses selected from Group III offerings of the Krieger School of Arts and Sciences Master of Science in Biotechnology program and/or Group II offerings of the Whiting School Master of Science in Applied Biomedical Engineering program.

Requirements for Master of C.B.E. with a Concentration in Nano/Microtechnology

Nano and microtechnology involves the science and technology of extreme miniaturization. We live in an era wherein 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 and Microtechnology, a student must complete the four core courses listed above plus six electives (of the six at least three electives must be from below):

- 520.772 Advanced Integrated Circuits
- 540.604 Therapeutic and Diagnostic Colloids
- 540.612 Interfacial Phenomena in Nanotechnology
- 540.633 Engineering Aspects of Drug Delivery
- 540.640 Micro and Nanotechnology

Requirements for Master of C.B.E. with a Concentration in Biomaterials/Drug Delivery

The growth and diversity of polymer/biomaterials science and engineering has provided a wealth of opportunities for chemical engineers to develop new materials by manipulating chemical architecture or macromolecular morphology. Chemical engineers working in the biomaterials industry require a unique set of skills in the fundamentals of chemical engineering science and polymer/biomaterials science. To earn the Master of Chemical Engineering Biomaterials/Drug Delivery, students must complete the four core courses, plus six additional electives (of the six at least three electives must be selected from the following):

- 510.607 Biomaterials II
- 510.617 Advanced Topics in Biomaterials
- 510.619 Biopolymers Synthesis
- 540.633 Engineering Aspects of Controlled Drug Delivery
- 540.626 Introduction to Biomacromolecules
- 540.604 Therapeutic and Diagnostic Colloids
- 540.612 Interfacial Phenomena in Nanotechnology
- 540.633 Engineering Aspects of Drug Delivery

Program Electives

Group I: Whiting School Chemical and Biomolecular Engineering Elective Courses

- 540.626 Introduction to Biomacromolecules
- 540.633 Engineering Aspects of Drug Delivery
- 540.640 Micro and Nanotechnology

Group II: Whiting School Applied Biomedical Engineering Courses

- 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
- 580.625-626 Structure and Function of the Auditory and Vestibular Systems
- 580.632 Ionic Channels in Excitable Membranes

Group III: Krieger School Biotechnology Core Courses and Elective Courses

- 410.601 Advanced Biochemistry
- 410.602 Molecular Biology
- 410.603 Advanced Cell Biology I
- 410.624 Bioanalytical Chemistry
- 410.637 Bioethics

Additionally, students must complete two to three courses selected from Group III offerings of the Krieger School of Arts and Sciences Master of Science in Biotechnology program and/or Group II offerings of the Whiting School Master of Science in Applied Biomedical Engineering program.

Requirements for Master of C.B.E. with a Concentration in Colloids and Interfaces

The chemical, physical and biological properties of an interface often differ significantly from that of the bulk due to surface energetic and entropic effects. The composition and conformation of molecules at an interface are responsible for a wide range of phenomena observed in materials science and biology. Solid-liquid interfaces for example, are crucial in lubrication, biocompatibility, drug delivery and corrosion. Liquid-liquid and liquid-gas interfaces are important in lipid membrane fusion, water pollution and acid rain. Solid-gas interfaces are critical in heterogeneous catalysis. The course in this degree will also deal with the interaction of colloidal (microscale particles), stabilization and flocculation and the structuring of microparticles in 3D for photonic applications.

To earn the Master of Chemical Engineering/Colloids and Interfaces, a student must complete the four core courses listed above plus six electives which must include:

- 540.604 Therapeutic and Diagnostic Colloids
- 540.612 Interfacial Phenomena in Nanotechnology
- 540.633 Engineering Aspects of Drug Delivery

Program Electives
Chemical and Biomolecular Engineering

Graduate Programs

410.642 Economic Aspects of Biotechnology
410.644 Marketing Aspects of Biotechnology
410.645 Biostatistics
410.650 Legal Aspects of Biotechnology
410.656 Recombinant DNA Laboratory
410.657 Recombinant Protein Expression, Production, and Analysis

Additional Admission Requirements for Non-Chemical Engineering Majors

In order 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 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.

540.203 Engineering Thermodynamics
540.204 Applied Physical Chemistry
540.301 Kinetics Processes
540.303 Transport Phenomena I
540.304 Transport Phenomena II

Course Descriptions

540.203 Engineering Thermodynamics

Formulation and solution of material, 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 solution. Extensive use is made of classical thermodynamic relationships 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 permission of instructor. Corequisite: 110.202 Calculus III (Calculus of Several Variables).

540.204 Applied Physical Chemistry

Introduction of the methods used to solve phase and chemical equilibria problems. The basic thermodynamic relationships to describe phase equilibrium of single-component and multicomponent systems are developed. Thermodynamic models for calculating fugacity are presented. These include equations of state, liquid solution models, and fugacity estimation methods. Multicomponent phase equilibrium problems addressed are cover liquid-vapor, liquid-liquid, liquid-liquid-vapor, and solid-vapor. Basic thermodynamic relationships to describe chemical equilibria 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.

540.301 Kinetic Processes


**Prerequisites:** 540.203 Engineering Thermodynamics and 540.303 Transport Phenomena I, and either 540.202 or permission of instructor.

540.303 Transport Phenomena I

Introduction to the field of transport phenomena. Molecular mechanisms of momentum transport (viscous flow), energy transport (heat conduction), and 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. Exact solutions to steady state, isothermal unidirectional flow problems, to steady state heat and mass transfer problems. The analogies
between heat, mass, and momentum transfer are emphasized throughout the course.

**Prerequisite:** A grade of C or better in Calculus I, II, and III and 540.202 or permission of instructor. Corequisite: 500.303

**540.304 Transport Phenomena II**

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

**540.426 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, micromanipulation techniques, as well as rheology, applied to the study of polymers.

**Staff**

**540.427 Introduction to Polymer Science**
Topics include bonding in polymers, polymer morphology, molecular weight characterization, polymer solubility and solutions, transitions in polymers, condensation and free radical polymerization, copolymerization, rubber elasticity, viscoelasticity, polymer processing.

**Prerequisite:** Junior standing in engineering or the physical sciences.

**540.430 Protein Solution Thermodynamics**
Much of our current understanding of protein interactions has been from observations of bulk thermodynamic behavior, such as solubility, osmotic pressure, and adsorption. More recently, however, intermolecular forces have been measured directly for proteins using techniques such as surface force apparatus, atomic force microscopy, and osmotic pressure. The course will examine the relationship between forces in protein solutions and the macroscopic thermodynamic properties of protein solutions.

**Staff**

**540.431 Biochemical Engineering/Biotechnology**
Application of engineering principles in biochemistry and microbiology. Topics include a brief review of microbiology, fermentation kinetics, microbial growth models, recombinant DNA technology, cell line development, mass and energy balances, metabolic processes, transport phenomena in biotechnology systems, and recent advances in biotechnology.

**540.433 Engineering Aspects of Drug Delivery**
This course addresses the fundamental engineering behind the development and understanding of controlled drug delivery systems. Focus is placed on the encapsulation and delivery of therapeutic proteins and genes from polymeric devices due to their increasing prevalence and importance in pharmaceutical products. Routes of drug delivery to be covered include oral, transdermal, pulmonary, injection, and surgical implantation. Other topics to be covered include drug pharmacokinetics, protein, stability in polymers, and polymer encapsulation of cells for bioartificial organs.

**Prerequisite:** Junior standing or higher in engineering. Helpful background: polymer course (e.g., 540.427 or 580.440), transport phenomena (540.303), biochemistry, cell biology. This course is cross-listed with 540.633.

**540.435 Genome Engineering**
The interpretation of cellular functions at the genetic level and the application of this knowledge for technological innovation. Topics include bioinformatics, combinatorial biochemistry, genome shuffling, metabolic engineering, and bioremediation.

**Bettenbaugh, Ostermeier**

**540.440 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.

This course is cross-listed with 540.640.

**Gracias**

**540.441 Topics in Cellular Engineering**
Topics in Cellular Engineering will provide an overview of molecular biology fundamentals, an extensive review on extracellular matrix and basics of receptors, followed by topics on cell-cell and cell-matrix interactions at both the theoretical and experimental levels. Subsequent 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 process. Material on cell-cycle, apoptosis, metabolic engineering, and gene therapy will also be incorporated into the course. Cross-listed with 580.441.

**Konstantopoulos, Yarema**

**540.473 Interfacial Phenomena**
Course provides an overview of colloid and surface science. Topics include surface and interfacial tension and surface ener-
540.602 Cellular and Molecular Biotechnology of Mammalian Systems

Stebe

540.604 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, from highly targeted drug and gene 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 macro rheology, 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.

Wirtz, Hanes

540.612 Interfacial Phenomena in Nanotechnology
Nanotechnology is a new field that is still being defined, with concepts ranging from nanorobotics to nanomaterials. Whatever the outcome, engineering at the nanoscale will be dominated by surface science, as surface to volume ratios become large. Furthermore, self-assembly techniques, with which molecules can spontaneously assemble in ordered structures with nanometer length scales are ripe for exploitation to create new materials. In this class, the fundamentals of interfacial thermodynamics, interfacial interactions (e.g. van der Waals’ interactions, electrostatics, steric interactions), adsorption, self-assembly and specific interactions will be covered with an emphasis on how to exploit these ideas in application in nanotechnology.

Stebe

540.621-622 Advanced Chemical Engineering Thermodynamics I
A comprehensive examination of the fundamental laws, principles, and concepts of classical statistical thermodynamics. Detailed discussion of various topics such as the properties of pure fluids, the thermodynamics of flow processed, chemical reaction equilibria, and equations of state, solutions, and phase behavior.

Donohue, Katz, McHugh, Paulaitis

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

Wirtz

540.630 Thermodynamics and Statistical Mechanics for Chemical and Biomolecular Systems
We will develop equilibrium thermodynamics and statistical mechanics from the unified perspective of entropy maximization subject to constraints. After a brief review of 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. Time permitting, toward the end we will devote couple of lectures to modern developments in statistical mechanics that connect non-equilibrium work to equilibrium free energies.

Asthagiri

540.633 Engineering Aspects of Drug Delivery
This course addresses the fundamental engineering behind the development and understanding of controlled drug delivery systems. Focus is placed on the encapsulation and delivery of therapeutic proteins and genes from polymeric devices due to their increasing prevalence and importance in pharmaceutical products. Routes of drug delivery to be covered include oral, transdermal, pulmonary, injection, and surgical implantation. Other topics to be covered include drug pharmacokinetics,
protein, stability in polymers, and polymer encapsulation of cells for bioartificial organs.

Prerequisite: Junior standing or higher in engineering. Helpful background: polymer course (e.g., 540.427 or 580.440), transport phenomena (540.303), biochemistry, cell biology. This course is cross-listed with 540.433.

Hanes

540.640  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. This course is cross-listed with 540.440.

Gracias

540.642  Advanced Topics in Biochemical Kinetic Processes
Survey of kinetic/reactor phenomena of high relevance to industry and cutting-edge biomolecular engineering research. Topics to be covered include reactions with phase changes for the microelectronics industry, computational modeling of complex multiple reaction systems, enzyme kinetics (including inhibition, allostericity and cooperativity), pharmacokinetics, cell bioreactors, and intracellular kinetics relevant to metabolic engineering.

Betenaugh, Ostermeier, Hanes

540.644  Interfacial Phenomena in Nanostructured Materials
All materials 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 characteristic volume scale. General topics include the structure of nanostructured materials (characterization & 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).

Frechette, Erlebacher

540.652  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, 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.

Stebe, Konstantopoulos, Drazer

540.660  Computational and Experimental Design of Biomolecules
This course reviews current research problems in biomolecular design both from computational and experimental approaches. Current methods in structure prediction (folding, docking and design) will illustrate fundamental concepts in protein structure, biophysics, and optimization. Current research problems in evolution-based biomolecular engineering will illustrate principles in the design of biomolecules (i.e. protein engineering, RNA/DNA engineering), metabolic pathways, signaling pathways, genetic circuits and complex biological systems including cells.

Gray, Ostermeier

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.

Margulies

545.449  Statistical Design of Experiments
This course introduces the basic concepts which 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.

Loehe
545.451 Introduction to Colloids and Surface Science
The course provides an overview of colloid and surface science. Topics include surface and interfacial tension and surface energies (definitions and methods of measurement), interactions at solid-liquid interfaces, thermodynamics of fluid interfaces, phenomenology of colloidal systems (classification, preparation, and morphology), sedimentation and diffusion of fine particles in dispersed systems, and rheology of colloidal systems.

Middleton, Stebe

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.

Murray

545.642 Advanced Chemical Kinetics and Reactor Design
Complex reaction networks; Wei-Prater analysis; the Himmelblau-Jones-Bischoff method. Detailed coverage 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; fluidized bed and multiphase reactors.

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. Graduate courses in the focus areas of structural engineering, geotechnical engineering, and ocean engineering are offered in the Master of Civil Engineering program. Additional courses are available in the areas of mechanics, probabilistic methods, mathematics, environmental engineering and other associated areas of technology.

Students may choose to specialize in one of the three focus areas (sample selections of courses in these areas are listed below) or in the general civil engineering area by selecting courses from any of the three focus areas and other approved courses listed in this catalog. With prior approval of the program chair, students may add breadth to their program by selecting three of their elective courses from other offerings of the Whiting School of Engineering.

The Department of Civil Engineering maintains fully equipped laboratories for structures and structural dynamics, soil mechanics, fluid mechanics and water-wave mechanics with supporting computational facilities. These laboratories are available for both demonstrations and independent study.

Program Committee

A. Rajah Anandarajah, Program Chair  
Professor, Civil Engineering  
Whiting School of Engineering

Robert A. Dalrymple  
Professor, Civil Engineering  
Whiting School of Engineering

Patrick J. Hudson  
Senior Professional Staff, National Security Technology Department  
Applied Physics Laboratory

Benjamin Schafer  
Assistant Professor, Civil Engineering  
Whiting School of Engineering

Admission Requirements

Applicants must meet the general requirements for admission to graduate study outlined in this catalog. 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 emphasizes four focus areas: Structural Engineering, Geotechnical Engineering, Ocean Engineering and General Civil Engineering. Students may add breadth to their program by selecting three of their elective courses from other offerings of the Whiting School of Engineering.

Ten one-term courses, approved by the faculty adviser, must be completed within a period of five years. At least seven of the courses must be in civil engineering; however, appropriate courses from related or supporting fields are allowed with prior approval of the program chair. Up to two of the 10 required courses may be taken in research. Courses in the program must be at the 400-level or above. Unless prior approval is obtained from the program chair, at least five of the courses in the program must be 600-level or above.

Please refer to the course schedule published each term for exact dates, times, locations, fees and instructors. Courses numbered 600-level and above are open only to those students who are admitted to graduate study and to undergraduates who have satisfactorily completed appropriate prerequisites.

Core, Concentrations and Electives

The 10-course MCE program consists of two parts: (1) the core of the program, consisting of two civil engineering courses and one course in applied mathematics, and (2) electives, consisting of seven courses. Sample selections of courses in the four concentrations are presented below. Additional civil engineering courses are listed in this catalog. While some of these courses are offered in late afternoons and evenings, the remaining courses are offered during the day. Most 600- and 700-level courses are offered on a two-year cycle.

Required Core

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
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<tbody>
<tr>
<td>560.475</td>
<td>Advanced Soil Mechanics</td>
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<tr>
<td>560.729</td>
<td>Structural Mechanics</td>
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One of the Following:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
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<tr>
<td>535.441</td>
<td>Mathematical Methods for Engineers</td>
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<tr>
<td>615.441</td>
<td>Mathematical Methods for Physics and</td>
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<td></td>
<td>Engineering</td>
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Electives

Sample Structural Engineering Electives

<table>
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<tr>
<th>Course</th>
<th>Title</th>
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<tbody>
<tr>
<td>560.730</td>
<td>Finite Element Methods</td>
</tr>
<tr>
<td>560.752</td>
<td>Structural Dynamics</td>
</tr>
<tr>
<td>565.430</td>
<td>Structural Design with Timber, Masonry,</td>
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<tr>
<td></td>
<td>and Other Materials</td>
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<tr>
<td>565.492</td>
<td>Bridge Inspection Techniques</td>
</tr>
<tr>
<td>565.605</td>
<td>Advanced Reinforced Concrete Design</td>
</tr>
<tr>
<td>565.620</td>
<td>Advanced Steel Design</td>
</tr>
<tr>
<td>565.630</td>
<td>Prestressed Concrete Design</td>
</tr>
</tbody>
</table>
Civil Engineering

Sample Geotechnical Engineering Electives
560.732 Numerical Methods in Geomechanics
560.745 Retaining Structures and Slope Stability
565.625 Advanced Foundation Design
565.635 Ground Improvement Methods
565.645 Marine Geotechnical Engineering
565.742 Soil Dynamics
565.770 Fundamentals of Soil Behavior

Sample Ocean Engineering Electives
560.780 Coastal Engineering
560.781 Introduction to Water Wave Mechanics
560.782 Advanced Ocean Hydrodynamics
565.645 Marine Geotechnical Engineering
565.650 Port and Harbor Engineering

General Civil Engineering Electives
Any seven courses, including at least four civil engineering courses listed in this catalog.

Course Descriptions

Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors. Courses numbered 600-level and above are open only to those students who are admitted to graduate study and to undergraduates who have satisfactorily completed appropriate prerequisites.

560.435 Probability and Statistics in Civil Engineering
Development and applications of the analysis of uncertainty, including basic probability, statistics and decision theory, in civil engineering areas of soil mechanics, structures, transportation and water resources.
Prerequisite: 110.109.

560.475 Advanced Soil Mechanics
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, foundation spring constraints for superstructure analysis.
Prerequisite: 560.305.

560.729 Structural Mechanics
Basic solid mechanics for structural engineers. 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.
Prerequisite: 560.305 or equivalent.

560.732 Numerical Methods in Geomechanics
Prerequisite: Background in finite element analysis or permission of instructor.

560.745 Retaining Structures and Slope Stability
Prerequisite: 560.305 and 560.305 or equivalent.

560.752 Structural Dynamics
Prerequisite: 560.445 Advanced Structural Analysis or 560.455 Structural Mechanics.

Igusa
560.756 Earthquake Engineering
Corequisite: 560.752.

560.757 Random Fields
Stochastic field theory, as applied to 1-, 2-, and n-dimensional random processes. Descriptors of homogeneous and non-homogeneous random fields. Study of load average processes. Review of various other topics in random field theory and applications.

560.758 Random Vibration
Prerequisite: 560.752 or equivalent.

560.760 Structural Stability
Prerequisite: 560.445, 560.455, or equivalent.

560.780 Coastal Engineering
Coastal processes and their influence on engineering at the shoreline. Waves and currents, equilibrium beach profiles, littoral transport, shoreline modeling, and the behavior of tidal inlets. Additionally the impact of structures on the coastline is discussed.

560.781 Introduction to Water Wave Mechanics
The theories governing water waves are discussed. Linear wave will be explored in detail. Aspects of nonlinear waves will be presented.
Prerequisite: 535.119 Fluid Mechanics or equivalent.

560.782 Advanced Ocean Hydrodynamics
Fundamentals of fluid mechanics in the context of naval architecture and ocean/science engineering. Emphasis on topics selected from potential flow, added mass, model testing, lifting surfaces, and others.
Prerequisite: 535.119 Fluid Mechanics or equivalent.

565.430 Structural Design with Timber, Masonry, and Other Materials
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 included.
Prerequisite: 565.105 Theory of Structures I or 560.301 Theory of Structures. In addition, one previous design course is preferred.
Civil Engineering

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; consideration of partial prestress, composite sections, and slabs.
Prerequisite: 565.126 Structural Design II or 560.325 Concrete Structures.

565.635  Ground Improvement Methods
The 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.
Prerequisite: 560.330 Foundation Design and 560.475.

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 dead-weight anchors, pile foundations and anchors, penetration and breakout of objects on the seafloor, marine slope stability, soft ground improvement, marine dredging, and project planning.
Prerequisite: 565.121 Soil Mechanics or 560.305 Soil Mechanics.

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 berth 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.

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.
Prerequisite: 560.780 Coastal Engineering or 560.781 Introduction to Water Waves.

565.675  Hydrodynamics of Estuaries
Topics applied 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.
Prerequisite: 535.119 Fluid Mechanics or equivalent.

565.680  Independent Study in Civil Engineering
Permission of instructor required.

565.742  Soil Dynamics
Study of soil behavior under dynamic loading conditions: 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, foundation design for vibratory loadings.
Prerequisite: 560.305 or equivalent.

565.756  Earthquake Engineering

565.760  Fundamentals of Soil Behavior
Prerequisite: 560.305.

565.784  Bridge Design

565.800  Independent Study in Civil Engineering
Permission of instructor required.

565.801  Independent Study in Civil Engineering
Permission of instructor required.
Computer Science

The proliferation of computers and the expanding scope of information technology has 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 artificial intelligence, bioinformatics, computer engineering, data communications and networking, database systems, distributed computing, information assurance, software engineering, systems, theory, and visualization and human-computer interaction. 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

Ralph D. Semmel, Program Chair  
Principal Professional Staff  
Applied Physics Laboratory

Robert S. Grossman, Program Vice Chair  
Principal Professional Staff  
Applied Physics Laboratory

Eleanor Boyle Chlan  
Senior Lecturer in Computer Science  
Whiting School of Engineering

Marty Hall  
President  
Coreservlets.com, Inc.

Horace Malcom  
Principal Professional Staff  
Applied Physics Laboratory

Hashmat Malik  
President  
Software Productivity Strategists, Inc.

Richard Nieporent  
Senior Principal Engineer  
MITRE Corporation

John A. Piorkoski  
Principal Professional Staff  
Applied Physics Laboratory

John Sadovsky  
Scientist  
Lending Edge Design and Systems

Vincent G. Sigillito  
Principal Professional Staff (ret.)  
Applied Physics Laboratory

Scott Smith  
Professor and Chair, Computer Science Department  
Whiting School of Engineering

J. Miller Whisnant  
Principal 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 this catalog. 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:

I. Computer Science Courses:

1. Introduction to Programming Using Java or C++, one term
2. Data Structures—one term
3. Computer Organization—one term

II. Mathematics Courses:

1. One year of calculus—2 semesters or 3 quarters
2. 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
Bioinformatics

Computer science students may pursue a Master of Science in Computer Science with a Concentration 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 concentration 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, advisers 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.

Telecommunications and Networking Option

Computer science students may elect a telecommunications and networking option by taking seven courses in telecommunications and networking from the computer science and electrical and computer engineering programs. A maximum of three of those courses can be from the electrical and computer engineering area. Students are strongly encouraged to take courses from both the computer science and electrical and computer engineering areas. Students lacking an electrical engineering background or equivalent must take 625.260 Introduction to Linear Systems as an undergraduate prerequisite for 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 option are listed on the Telecommunications and Networking Option page.

Course Requirements

Ten courses, approved by an adviser, must be completed within five years. At least eight courses must be from the computer science curriculum, and of those, three must be from the same concentration area. At least two of the computer science 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 electives 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.

Foundation Courses

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

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

Foundation Course Waivers

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.

Undergraduate Courses

- 605.201 Introduction to Programming Using Java
- 605.202 Data Structures
- 605.203 Discrete Mathematics
- 605.204 Computer Organization
- 605.205 Molecular Biology for Computer Scientists

Graduate Courses

I. Software Engineering

- 605.401 Foundations of Software Engineering
- 605.402 Software Analysis and Design
- 605.404 Object-oriented Programming with C++
- 605.405 Conceptual Design for High-Performance Systems
- 605.407 Agile Software Development Methods
- 605.408 Software Project Management
- 605.702 Service-Oriented Architecture
- 605.703 Component-Based Software Engineering
- 605.704 Object-Oriented Analysis and Design
- 605.705 Software Safety
- 605.706 Software Systems Engineering
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<th>Course Code</th>
<th>Course Title</th>
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<tr>
<td>605.707</td>
<td>Software Patterns</td>
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<td>605.708</td>
<td>Tools and Techniques of Software Project Management</td>
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<td>605.709</td>
<td>Seminar in Software Engineering</td>
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<tr>
<td><strong>II. Systems</strong></td>
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<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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<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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<td>605.715</td>
<td>Software Development for Real-Time Systems</td>
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<tr>
<td>605.716</td>
<td>Modeling and Simulation of Complex Systems</td>
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<tr>
<td><strong>III. Theory</strong></td>
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<tr>
<td>605.421</td>
<td>Foundations of Algorithms</td>
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<tr>
<td>605.423</td>
<td>Applied Combinatorics and Discrete Mathematics</td>
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<td>605.424</td>
<td>Logical Foundations of Computer Science</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>605.723</td>
<td>Signal Processing</td>
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<tr>
<td>605.725</td>
<td>Queuing Theory with Applications to Computer Science</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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<td><strong>IV. Information Assurance</strong></td>
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<tr>
<td>605.431</td>
<td>Principles of Information Assurance</td>
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<td>605.432</td>
<td>Public Key Infrastructure and Managing E-Security</td>
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<td>605.433</td>
<td>Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms</td>
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<td>605.434</td>
<td>WWW Security</td>
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<tr>
<td>605.731</td>
<td>Network Security</td>
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<tr>
<td>605.732</td>
<td>Cryptology</td>
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<tr>
<td>605.733</td>
<td>Java Security</td>
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<tr>
<td>605.734</td>
<td>Information Assurance Architectures and Technologies</td>
</tr>
<tr>
<td>605.735</td>
<td>Authentication Technologies</td>
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<td><strong>V. Database Systems and Knowledge Management</strong></td>
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<tr>
<td>605.441</td>
<td>Principles of Database Systems</td>
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<td>605.444</td>
<td>XML: Technology and Applications</td>
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<td>605.445</td>
<td>Artificial Intelligence</td>
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<td>605.447</td>
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<td>605.741</td>
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<td>605.743</td>
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<td>605.744</td>
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<td>Reasoning Under Uncertainty</td>
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<td>605.746</td>
<td>Machine Learning</td>
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<td>605.747</td>
<td>Evolutionary Computation</td>
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<td><strong>VI. Bioinformatics</strong></td>
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<tr>
<td>605.451</td>
<td>Principles of Computational Biology</td>
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<td>605.452</td>
<td>Biological Databases and Database Tools</td>
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<td>605.456</td>
<td>Computational Drug Discovery and Development</td>
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<td>605.751</td>
<td>Computational Aspects of Molecular Structure</td>
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<td>605.753</td>
<td>Computational Genomics</td>
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<td>605.754</td>
<td>Analysis of Gene Expression</td>
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<td>605.755</td>
<td>Systems Biology</td>
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<tr>
<td>605.759</td>
<td>Independent Project in Bioinformatics</td>
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</table>

**Additional choices:**
The following courses may be counted toward a 3-course concentration in Bioinformatics.

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<tr>
<th>Course Code</th>
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<tr>
<td>605.716</td>
<td>Modeling and Simulation of Complex Systems</td>
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<tr>
<td>605.743</td>
<td>The Semantic Web</td>
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</table>

**VII. Visualization and Human-Computer Interaction**

<table>
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<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tr>
<td>605.461</td>
<td>Principles of Computer Graphics</td>
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<tr>
<td>605.462</td>
<td>Data Visualization</td>
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<tr>
<td>605.463</td>
<td>Image Processing</td>
</tr>
<tr>
<td>605.465</td>
<td>Natural Language Processing</td>
</tr>
<tr>
<td>605.761</td>
<td>Applied Computer Graphics</td>
</tr>
<tr>
<td>605.766</td>
<td>Human-Computer Interaction</td>
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</tbody>
</table>

**VIII. Data Communications and Networking**

(For the telecommunications and networking options in electrical and computer engineering and computer science, please see the Telecommunications and Networking page of this catalog.)

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<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tr>
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<td>Principles of Data Communications Networks</td>
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<td>605.472</td>
<td>Computer Network Architectures and Protocols</td>
</tr>
<tr>
<td>605.475</td>
<td>Protocol Design</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>605.773</td>
<td>High-Speed Networking Technologies</td>
</tr>
<tr>
<td>605.774</td>
<td>Network Programming</td>
</tr>
<tr>
<td>605.775</td>
<td>Optical Networking Technology</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>
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</table>

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Computer Science

IX. Distributed Computing

605.481 Distributed Development on the World Wide Web
605.484 Collaborative Development with Ruby on Rails
605.781 Distributed Objects
605.782 Web Application Development with Servlets and JavaServer Pages (JSP)
605.784 Enterprise Computing with Java

605.785 Web Services: Framework, Process, and Applications
605.786 Enterprise System Design and Implementation
605.787 Rich Internet Applications with Ajax

Special Topics

605.791 New Technical Ventures
605.801 Independent Study in Computer Science I
605.802 Independent Study in Computer Science II

Course Descriptions

Computer science course offerings are numbered to indicate their primary concentration area.

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.

Note: This course DOES NOT count toward the Master of Science in Computer Science degree.

Chittargi, Ferguson, 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 trade-offs 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.

Note: This course DOES NOT count toward the Master of Science in Computer Science degree.

Chlan, Resch, Tijaden

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: Differential and integral calculus.

Note: 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. This course DOES NOT count toward the Master of Science in Computer Science degree.

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.

Prerequisite: 605.202 Data Structures is recommended.

Note: This course DOES NOT count toward the Master of Science in Computer Science degree.

Malcom, Schappelle, Snyder, Whisnant, White

605.205 Molecular Biology for Computer Scientists
This course is designed for students seeking to take bioinformatics courses, but who lack the biological prerequisites. The course will cover essential aspects of cell biology, biochemistry, and molecular biology. Topics include chemistry; macro-molecules and organization of the cell; overview of enzymes, metabolism, cell cycle and signal transduction; DNA structure, central dogma of molecular biology, the genetic code, and gene expression and its regulation; and polymerase chain reaction and genome sequencing.

Note: This course DOES NOT count toward the Master of Science in Computer Science degree.

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.

Chavis, Gieszl, Schappelle, Yufik

605.402 Software Analysis and Design
This course offers a unified approach to analysis and design of complex software systems. Both structured and object-oriented techniques are discussed. Included are comprehensive studies of the rationale behind the use of design methods that have been demonstrated to produce effective designs for sequential and distributed concurrent systems. Real-time issues are considered. Insights gained in the course will enable students to critically evaluate the contribution of popular methodologies to the underlying problems of requirements analysis and software design.

Prerequisite: Recent professional experience in software development would be helpful.

Staff

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.

Prerequisite: Knowledge of Java or C.

Summer, Fall, Spring Boon, Demasco, Ferguson, Pierson

605.405 Conceptual Design for High-Performance Systems
Recent data indicates that 80 percent of all new products or services in the U.S. 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.

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, Test-Driven Development, and Feature-Driven Development. These methods promote teamwork, rich concise communication, and the frequent delivery of running, tested systems containing the highest priority customer features. Agile methods will be contrasted with common workplace practices, and traditional methods such as CMMI, PMI/PMBOK, and RUP as well as examples of agile adoption in industry will be discussed. Additional topics include team dynamics, collaboration, software quality, and metrics for reporting progress.

Prerequisites: 605.401 Foundations of Software Engineering

Menner

605.408 Software Project Management
(formerly 605.403)
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 software 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.

Bowers, Winston
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.

Boser, Malcom, Snyder, Whisnant

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.

Noble

605.414 System Development in the UNIX Environment
(formerly 605.714)
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.

Prerequisite: Familiarity with UNIX, experience with C++ or C.

Ching, Noble, Russell

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 breath-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.

Ferguson

Prerequisite: 605.202 Data Structures or equivalent.

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. (This course is the same as 625.417 Applied Combinatorics and Discrete Mathematics.)

Whisnant

605.424 Logical Foundations of Computer Science
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.

Waddell
605.431 Principles 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 product and system evaluation criteria. Policy considerations are examined with respect to the technical nature of enterprise security as represented by government regulations for software with cryptographic capability. 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 a data processing environment, as well as the computer "crime" potential of such systems. The class examines several data encryption algorithms.

Heinbuch, Podell

605.432 Public Key Infrastructure and Managing E-Security

This course describes public key technology and related security issues. Public Key Infrastructure (PKI) components are explained, and support for e business and strong security services required by various applications is described. The role of digital certificates, the importance of certificate policy and certification practices, and essential aspects of key management that directly impact assurance levels and electronic services are addressed. The capabilities of PKI and digital signatures are examined in the context of the business environment, including applicable laws and regulations. The essential elements for successful PKI planning and rollout are discussed, and the state of PKI and interoperability issues are presented.

Kumar, Mitchel

605.433 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. 

Prerequisite: Basic understanding and working knowledge of the materials presented within the study modules.

Kalb

605.434 WWW Security

This course examines issues associated with making web applications secure. The principal focus is on server-side features such as CGI security, proper server configuration, and firewalls. The course also investigates protection of the connection between a client and server by encrypting the data stream (e.g., with SSL) or by keeping certain data private from the server system (e.g., via third party transaction protocol like SET or digital cash). Finally, the course explores client-side vulnerabilities associated with browsing the web, such as system penetration, information theft, identity spoofing, and denial of service attacks. Related topics such as malicious e-mails, web scripts, cookies, web bugs, spyware, and software security will also be discussed. Labs are included to enable students to probe more deeply into security issues and to develop and test potential solutions.

Prerequisite: Basic understanding of computer operating systems.

Ching

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.

Immer, Kung, Liu, Semmel

605.444 XML: Technology and Applications

This course covers the concepts, technology, and applications of XML (Extensible Markup Language), especially to Web-based technologies. The course concentrates on XML fundamentals and associated technologies, and processing XML using Java. Topics covered include the XML Specification; XML Namespaces; Document Type Definitions (DTDs); XML Schemas; XML Transformation (XSLT); XML Links and
XML Pointers; and parsing XML using the Document Object Model (DOM) and Simple API (Application Programming Interface) for XML (SAX), the Java API for XML Processing (JAXP), and the Java Document Object Model (JDOM). Additional topics may be drawn from Cascading Style Sheets (CSS); XQuery; the Simple Object-Oriented Protocol (SOAP); Web Services Description Language (WSDL); Universal Description, Discovery and Integration (UDDI); applications of XML such as RDF; and the architecture of Web Service, EAI, and B2B systems using XML. (This course is the same as 635.444 XML: Technology and Applications.)

Prerequisite: 605.481 Distributed Development on the World Wide Web or equivalent Java experience.

Chittargi, Silberberg

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.

Sheppard

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. (This course is the same as 625.438 Neural Networks.)

Fleischer, Whisnant

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; and 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; a course in molecular biology and a course in cell biology or biochemistry are highly recommended.

Przytycka

605.452 Biological Databases and Database Tools

The sequencing of the human genome and the emerging intense interest in proteomics and molecular structure have caused an enormous explosion in the need for biological databases. The first half of this course surveys a wide range of biological databases and their access tools and seeks to develop proficiency in their use. These include genome and sequence databases such as GenBank and Ensemble, as well as protein databases such as PDB and SWISSPROT, and their analysis tools. Tools for accessing and manipulating sequence databases will be covered, such as BLAST, multiple alignment, Perl, and gene finding tools. Advanced, specialized and recent popular databases such as KEGG, BioCyc, HapMap, Allen Brain Atlas, Afcs, etc., will be surveyed for their design and use. The second half of this course focuses on the design of biological databases including the computational methods to create the underlying data, as well as the special requirements of biological databases such as interoperability, complex data structures consisting of very long strings, object orientation, efficient interaction with computational operators, parallel and distributed storage, secure transactions and fast recall. Students will create their own small database as a project for the course as well as complete homework assignments using databases.

Prerequisites: 605.441 Principles of Database Systems or 410.634 or working knowledge of SQL, and a prior course in molecular biology or cell biology (605.205 or 410.602).

Notes: Students who do not have a prior background in databases can succeed in this course by concurrent self-study of relational databases and SQL using a book such as Database Solutions: A Step by Step Guide to Building Databases, by Thomas.

Hobbs

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 translation 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 bio-
technology. 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.

**605.461 Principles of 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.

**Prerequisite:** Familiarity with linear algebra.

**Kumar**

**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.

**Prerequisite:** Experience with data collection/analysis in data-intensive fields or background in computer graphics (e.g., 605.461) is recommended.

**Nesbitt**

**605.463 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.

**Prerequisite:** Familiarity with Fourier transforms.

**Chlan and Corrigan and Waters**

**605.465 Natural Language Processing**

This course covers the concepts and methods for processing natural language by computer. Topics include pattern matching, parsing, the role of the dictionary and lexical acquisition, semantic interpretation, anaphoric reference, plan recognition, discourse analysis, and text generation. Applications are drawn from natural language interfaces, text processing systems, advisory systems, and interaction with speech recognizers. A "hands on" natural language processing development tool is used.

**Prerequisite:** 605.445 Artificial Intelligence.

**Staff**

**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, 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; synchronous and asynchronous transmission; RS232 physical layer interface standards; FDM, TDM, and STDM multiplexing techniques; inverse multiplexing; analog and digital transmission; V series modem standards; PCM encoding and T1 transmission circuits; LRC/ VRC and CRC error detection techniques; Hamming and Viterbi forward error control techniques; BSC and HDLC data link layer protocols; Huffman, MNP5 and V.42bis data compression algorithms; circuit, message, packet and cell switching techniques; ISDN, frame relay, SMDS and ATM networks; minimum spanning tree, Esau-Williams and Add network topology optimization algorithms; reliability and availability, TRIB, and queuing analysis topology optimization techniques; and circuit costing.

**Boules, Nieporent, Smith**

**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, and 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; internetworking; 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; and OSI transitioning tools, multiprotocol networks, and encapsulation, tunneling and convergence techniques.

Prerequisite: 605.471 Principles of Data Communications Networks.

May, Nieporent

605.475 Protocol Design

This course is an introduction to the formal design, specifications, and validation of computer protocols. The course focuses on the principles of protocol specification and validation. The following topics form the major part of the course: structured protocol design, protocol models, protocol validation, protocol correctness requirements, and protocol design.

Prerequisites: 605.471 Principles of Data Communications Networks and 605.771 Wired and Wireless Local and Metropolitan Area Networks, or 605.472 Computer Network Architectures and Protocols, or 605.477 Internetworking with TCP/IP 1.

Zheng

605.477 Internetworking with TCP/IP 1

This course investigates the detailed architecture, design, and technology that unifies various packet switching networks built around ARPANET technology and local area networks, such as Ethernet, into a common network known as the Internet. The common underlying internetworking concept that enables these disparate networks to function as a unified whole is manifested in the connectionless Internet Protocol (IP). IP and access mechanisms, such as SLIP and PPP, are examined in detail, and the error control message protocol (ICMP) is also described. The protocols used by the hosts and other devices attached to these networks that function above the IP are investigated. Communications-related protocols analyzed in detail include the connection oriented, reliable Transport Control Protocol (TCP); and the connectionless User Datagram Protocol (UDP). Dynamic IP routing and subnet routing using protocols both interior and exterior to the autonomous systems (AS) are studied, including RIP, OSPF and BGP. The Application Programming Interface (API) in the form of Berkeley Sockets for TCP and UDP is also investigated. Finally, protocols for user applications are examined, such as the File Transfer Protocol (FTP), Simple Mail Transfer Protocol (SMTP), and TELNET remote login protocol.

Prerequisite: 605.471 Principles of Data Communications Networks.

Scott

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), and 3G widebandCDMA (W-CDMA).

Prerequisite: 605.471 Principles of Data Communications Networks.

Shyy

605.481 Distributed Development on the World Wide Web

This course examines three major topics in the development of applications for the World Wide Web. The first is web site 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).

Evans, Naber, Shyamsunder, Spiegel

605.484 Collaborative 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.

Prerequisite: 605.481 Distributed Development on the WWW or equivalent.

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.

Prerequisite: 605.401 Foundations of Software Engineering. 605.481 Distributed Development on the World Wide Web and 605.704 Object Oriented Analysis and Design or equivalent experience are highly recommended.

Weimer

605.703 Component-Based Software Engineering

(formerly 605.703 Software Reuse)

Component-Based Software Engineering (CBSE) is concerned with the development of software-intensive systems from reusable parts, the development of reusable parts, and with the maintenance and improvement of systems by means of component replacement and customization. In contrast to the opportunistic, “do it when you can” approach, this course is an introduction to the systematic application of CBSE to the development of software intensive systems. This course will cover both the consumer side of the CBSE model (the development of systems from components and frameworks) and the producer side of the CBSE model (developing components, creating design patterns, and building whole frameworks). Though the course will focus primarily on CBSE theory and strategies, students will participate in a class project in which they will act as CBSE consumers or producers. The class project will require basic skills using the Microsoft Windows/Visual Studio.Net platform, which will be covered in an optional set of exercises and tutorials.

Prerequisites: Experience with an object-oriented language such as Java or C++.

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).

Prerequisite: Experience in object-oriented programming using a language such as Java or C++.

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 "safeware," and case studies are presented regarding catastrophic situations that resulted from software and system faults which could have been avoided. Specific techniques of risk analysis, hazard analysis, fault tolerance, and safety tradeoffs within the software engineering paradigm are discussed.

Gieszl

605.706 Software Systems Engineering

(formerly 605.706 The Software Development Process)

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.

Prerequisite: One software engineering course beyond 605.401, Foundations of Software Engineering.

Siegel and Donaldson, White
605.707 Software 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.
Prerequisite: 605.404 Object-Oriented Programming with C++ or permission of instructor.

Lindberg, Stanchfield

605.708 Tools and Techniques of Software Project Management
(formerly 605.701 Software Size and Cost Estimating)
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 software 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 Personal Process Improvement and the tools and techniques that can be used by an individual to monitor task performance. Finally, the course investigates personnel staffing, recruiting, and retention strategies in an environment where employee demographics are radically changing.

Bowers

605.709 Seminar in Software Engineering
This course examines the underlying concepts and latest topics in software engineering. Potential topics include effective software development techniques such as agile and extreme programming; use of UML to define testing strategies; useful development tools and environments; patterns; metrics issues in system generation; teamwork in successful developments; and training aspects of CMM. Each student will select and report on a software engineering topic, perform independent reading, 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.
Prerequisite: One software engineering course beyond 605.401 Foundations of Software Engineering.

Grossman

605.715 Software Development for Real-Time 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.
Prerequisite: Programming experience with Java.

Ferguson

605.716 Modeling and Simulation of Complex Systems
(formerly 605.752 Simulation of Biological and 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.
Prerequisite: 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.
This course may be counted toward a three course concentration in Bioinformatics.

Addison
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, and discrete mathematics.

Boon, Sadowsky

605.722 Computational Complexity
This course introduces the field of computational complexity and its applications in computer science and cryptography. The subject explores foundational questions of the relative costs, primarily in computation time and storage, for the computational solutions of different classes of problems, over all possible algorithms. Basic concepts of polynomial, NP, and NP-Complete problems are developed in both intuitive and rigorous forms. Methods for determining tractability of problems, the polynomial hierarchy, techniques and complexity of approximation algorithms, and current topics in complexity are also covered. The course also covers complexity topics in cryptography, including classical cryptosystems, public key, one-way-function cryptosystems, the RSA system, protocols for impossible problems in communication, and zero-knowledge-based systems. All background in theoretical computer science is developed as needed in the course.

Prerequisites: Exposure to algorithm design heuristics and discrete mathematics would be helpful but is not required.

Zaret

605.723 Signal Processing
This course introduces signal processing, with an emphasis on digital signal processing, from the perspective of computer science, providing the theoretical and practical framework for understanding signal processing algorithms, architectures, and applications. Basic concepts for signal analysis, including signal presentation, time and frequency domains, spectral analysis, and noise are introduced. Components of signal processing, such as systems, filters, correlators and convolvers, and adaptive processes are defined. Architectures and algorithms, including fast algorithms for Fourier transforms, correlation, convolution, spectral estimation, graphical techniques, and DSP processor devices are presented. Applications including speech, communications, music, and biological signal processing are surveyed. Students will complete several homework problem sets and a term project, and will program using Java, C, C++, or Matlab. No previous knowledge of signal processing, real analysis, complex analysis, or Fourier transforms is assumed.

Prerequisites: 605.421 Foundations of Algorithms, or equivalent, and linear algebra, or permission of instructor.

Sadowsky

605.725 Queuing Theory with Applications to Computer Science
Queues are a ubiquitous part of everyday life; common examples are supermarket checkout stations, help desks 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 625.734 Queuing Theory with Applications to Computer Science.)

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

Nickel

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.

Prerequisite: Familiarity with linear algebra.

Sunday

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 of 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.

605.731 Network Security
This course discusses concepts and issues pertaining to network security; examines methods and technologies for securing wired/wireless computer systems, communications network systems, and converging systems; and surveys wired/wireless network security standards. Topics include Next Generation Networks (NGN) security architecture, applied cryptography for e-commerce, Wireless Local Area Network (WLAN) security, WLAN security countermeasures, wired/wireless Public Key Infrastructure (PKI), federated identity and secure network management, security issues for IETF (Internet Engineering Task Force) NEMO (Network Mobility), NEA (Network Endpoint Assessment), and IPv6 transition/co-existence. Selected network security technologies are introduced including Virtual Private Networks (VPN); Multiprotocol and Generalized Multiprotocol Label Switching (GMPLS) IPv6 transition, co-existence, and security issues; IP Telephony and attacks against an IP telephony network; Session Initiation Protocol (SIP) and SIP Security; and IP telephony security issues. Selected examples of current technology issues that impact network security are also discussed. Examples include current developments in WLAN, WiMAX (Worldwide Interoperability for Microwave Access), and 3rd Generation Partnership Project (3GPP) IP Multimedia Subsystem (IMS) security and IPv6 peer-to-peer (P2P) services, VPN key management, and Cisco Unified Communications Manager (CallManager) Security Design Issues.

Podell

605.732 Cryptology
This course provides an introduction to current research in cryptography. It begins with a survey of classical cryptographic techniques. It then develops the concepts from complexity theory and computational number theory that provide the foundation for much of the contemporary work in cryptography. The remainder of the course focuses on this contemporary work. Topics include symmetric block ciphers and the Advanced Encryption Standard, public key cryptosystems, digital signatures and authentication protocols, and quantum cryptography. All background in theoretical computer science is developed as needed in the course.

May, Zaret

605.733 Java Security
(formerly 605.733 Java and Web Services 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 "and boxes"; (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.

Prerequisite: 605.481 Distributed Development on the WWW or equivalent. Basic knowledge of XML. 605.431 Principles of Information Assurance or 605.434 WWW Security would be helpful but is not required.

Llanso

605.734 Information Assurance Architectures and Technologies
(formerly 605.734 Information Assurance)
Once only the concern of the military and financial communities, security has become a critical issue for reliable information systems. As a result, vendors are offering an array of security features and products to address system security concerns. Yet, as more security features and products become available, the number of system security failures continues to rise. The question that must be asked is how much can the security products be trusted to perform correctly and address system security requirements? This course will discuss the assurance issues associated with security technology ranging from formal models to design and development. The evolution of security criteria will also be addressed, from the development of the Orange Book to the Common Criteria, and the impact of those criteria on security developments will be described. High-assurance security projects will be reviewed to understand their security architectures, features, and development. These projects will be compared and contrasted with current commercial security products and efforts, such as Microsoft's Trustworthy Computing effort. The course will also discuss how to build systems that avoid the various types of flaws which exist in current systems (e.g., buffer overflows, race conditions, and covert channels).

Prerequisite: 605.431 Principles of Information Assurance is recommended but not required.

Ziegler
605.735  Authentication Technologies  
(formerly 605.735 Biometrics)

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 authentication process involves at least two entities: the one requiring authentication and the one to be authenticated. This course explores the underlying technology, the role of authentication in Information Assurance, evaluation of authentication processes, and the practical issues of authentication. Several different categories of authentication will be explored: Human-to-Machine (humans using biometrics, tokens and passwords for verification by a machine), Machine-to-Machine (one machine verifying another), and Machine-to-Human (humans verifying a machine). Case studies of authentication system implementations are presented. 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 system. Students will present a research project that reflects an understanding of key issues in authentication.

Prerequisites: 605.432 Public Key Infrastructure and E-Security.

Rhude

605.741  Distributed Database Systems

This course investigates principles of distributed database systems, including design and architecture, query processing, transaction management, locking, recovery, and RAID technology. The course also covers JDBC programming through a variety of interfaces including stand-alone Java programs, Java applets on web browsers, and Common Gateway Interface programs on web browsers. The course blends theory with practice, and students will use distributed database concepts to develop JDBC applications and JDBC drivers for implementing web-based distributed databases.

Prerequisites: 605.441 Principles of Database Systems, and 605.481 Distributed Development on the World Wide Web or equivalent knowledge of Java and HTML.

Silberberg

605.743  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 throughout the course, including the life sciences, knowledge management, electronic commerce and web services choreography. Domain-specific implementation strategies such as LSID (Life Sciences Identifier) and various vertical ontologies will be addressed.

Prerequisite: 605.444 XML: Technology and Applications or equivalent.

Addison

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.

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.

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.
Computer Science

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.

Prerequisite: 605.445 Artificial Intelligence is recommended but not required.

Sheppard

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 schema; 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.

Prerequisite: 605.445 Artificial Intelligence is recommended but not required.

Sheppard

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, 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: A course in molecular biology and a course in cell biology or biochemistry are highly recommended.

Panchenko and Przytycka

605.753 Computational Genomics

This course focuses on current problems of computational genomics. Students will use bioinformatics software and learn the principles underlying a variety of bioinformatics algorithms. In addition, students will explore and discuss bioinformatics research, and develop software tools to solve bioinformatics problems. Topics include analyzing eukaryotic, bacterial, and viral genes and genomes; finding genes in genomes and identifying their biological functions; predicting regulatory sites; assessing gene and genome evolution; and analyzing gene expression data.

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

Ermolaeva

605.754 Analysis of Gene Expression

The rapid popularization of microarray technology has led to an explosion in the collection of gene expression data. After a brief survey of existing gene expression software tools, this course emphasizes the development of original algorithms and data mining techniques for analyzing gene expression data. This course covers statistical and analytical methods and software development for the analysis of gene expression data. Topics include (1) a brief survey of existing software for microarray analysis (normalization, differential expression, and clustering); 2) algorithms, database design and data mining techniques for gene expression data; and 3) detailed coverage of analysis and reverse engineering of gene regulatory networks, including relevance networks, Boolean networks and continuous networks. Both static data and time series data will be considered. The student will develop sufficient expertise in both the underlying analysis and statistical theory to develop new algorithms and software to analyze gene expression data. Students will complete several software assignments including the design of a new algorithm for gene expression analysis.

Prerequisites: 605.205 or a course in molecular biology or cell biology, and a course in probability and statistics. Working knowledge of C or JAVA. JHU Online Orientation Course.

Note: 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.

Addison

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 datasets 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. As a course project, students will develop a model of a signal transduction or metabolic pathway.

Prerequisites: Courses in molecular biology (605.205 or 410.602) and differential equations.

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 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.

605.761 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.

Prerequisite: 605.461 Principles of Computer Graphics or familiarity with three-dimensional viewing and modeling transformations.

Nesbitt

605.766 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 web site 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. (This course is the same as 635.721 Human-Computer Interaction.)

Montemayer

605.771 Wired and Wireless Local and Metropolitan Area Networks
(formerly 605.771 Local 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 carrierband 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.

Prerequisite: 605.471 Principles of Data Communications Networks

Hsu, Nieporent

605.772 Network Management
Network management (NM) refers to all the functions, facilities, tools, communications interfaces, protocols, and human resources necessary to monitor and maintain communications networks and plan for their growth and evolution. NM includes investigation of day-to-day operations and administration of the networks. Within this framework, various aspects of managing voice and data networks are covered in this course. Management of specific network elements such as circuit and packet switches, multiplexers, and modems are addressed. The course also covers the concepts and fundamentals of NM standards such as OSI management standards and Simple Network Management Protocol (SNMP), which is a de facto standard.

Prerequisites: 605.771 Wired and Wireless Local and Metropolitan Area Networks, 605.472 Computer Network Architectures and Protocols, 605.477 Internetworking with TCP/IP, or 635.411 Foundations of Networking and Telecommunications.

Krishnan, Malik

605.773 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.

Prerequisite: 605.471 Principles of Data Communications.

Krishnan

605.774 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.

Noble

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 service 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, FTTP, 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.

Prerequisite: 605.773 High-Speed Networking Technologies, or permission of the instructor.

Krishnan

605.777 Internetworking with TCP/IP II
This course builds on the foundation established in 605.477, Internetworking with TCP/IP I. Changes are being made in the infrastructure, operation, and protocols of the Internet to provide the performance and services needed for real-time applications. This course first examines the current architecture and operation of the Internet. The classful addressing concept will be introduced and the mapping of Internet addresses to physical addresses is discussed along with the extensions that have been made to the addressing paradigm, including subnet addressing, classless addressing, and network address translation. The performance enhancements being developed to provide quality of service (QoS) over the Internet and to provide faster routing through the use of IP switching techniques are discussed. Techniques for providing multicasting and mobility over the Internet are examined. Security considerations are addressed by examining Virtual Private Networks and the use of IP Security (IPSec) protocols. The next generation IP protocol (IPv6) is introduced, and the changes and enhancements to the IP protocol operation and to the addressing architecture are discussed in detail. Finally, the development of the Voice Over IP (VoIP) application and the convergence of circuit switching and packet switching are discussed. Topics include subnet addressing, CIDR, DHCP, DNS, NAT, IntServ, DiffServ, RSVP, GIP, MPOA, IP Switching, Tag Switching, MPLS, IP Multicast, IGMP, Reliable Multicast, Multicast Routing Protocols, IP Mobility Home Agents and Foreign Agents, Message Tunneling, Proxy and Gratuitous ARP, PPTP, L2F, L2TP and SOCKSv5, VPN security, IPSec, Encapsulating Security Payload header, Authentication Header, Security Association, IPv6 Addressing, IPv6 protocol and extension headers, Neighbor Discovery, IPv6 Stateless Address Autoconfiguration, DHCPv6, VoIP, H.323 Gateways and Gatekeeper, SIP, SDP, RTP, MGCP, Megaco/H.248.

Prerequisite: 605.477 Internetworking with TCP/IP I.

Nieporent

605.778 Voice over IP
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
Finally, enterprise services will be discussed, including the Java (JDBC), data access patterns, and the Java Persistence API. Access tier discussion will focus on Java Database Connectivity as asynchronous business processing will be described. The Data business processing and message-driven beans and timers for transactions. For the Business Logic Tier, session beans for synchronous emphasis on integrating the web tier with enterprise applications. For the web access tier, the Chittargi, Hall

**605.781 Distributed Objects**

This course provides an introduction to the development of client/server and peer-to-peer applications using distributed technology. The course focuses on the services and facilities provided by object-oriented middleware systems such as CORBA, COM, and Java/RMI. Topics include interface definition languages (IDL), static and dynamic invocation interfaces, object references, distributed resource optimization, and concurrency control. Students will develop software in C++ for both homework and a project.

*Prerequisites:* 605.404 Object Oriented Programming with C++ or equivalent experience.

Lindberg, Pole

**605.782 Web Application Development with Servlets and JavaServer Pages (JSP)**

This project-oriented course investigates techniques for building server-side programs for dynamically generated Web sites, electronic commerce, Web-enabled enterprise computing, and other applications that require WWW access to server-based resources. Particular attention will be paid to methods for making server-side applications efficient, maintainable, and flexible. Topics include handling HTTP request information, generating HTTP response data, processing cookies, tracking sessions, designing custom JSP tag libraries, and separating content from presentation through use of JavaBeans components and the MVC (Model 2) architecture.

*Prerequisite:* 605.481 or equivalent Java experience.

Chittargi, Hall

**605.784 Enterprise Computing with Java**

This course covers enterprise computing technologies using Java Enterprise Edition (Java EE). The course describes how to build multi-tier 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.

*Prerequisite:* 605.481 Distributed Development on the WWW or equivalent.

Felicson, Shyamsunder, Stafford, Weimer

**605.785 Web Services: Framework, Process, 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 the stack of three emerging standard protocols: Simple Object Access Protocol (SOAP), Web Services Description Language (WSDL) and Universal Description, Discovery and Integration (UDDI). Students will also learn how to describe, expose, discover, and invoke software over the Web using the Java-centric technologies and APIs for XML for documents processing, JAXP, JAXRPC, SAAJ, JAXM, JAXR and JAXB. A comparison of Java-based and other web services implementation platforms will also be presented. 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. WSI 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: Technology and Applications or equivalent XML and Java programming experience; knowledge of the J2EE platform and programming model is recommended.

Felicson

**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.

*Prerequisite:* 605.784 Enterprise Computing with Java. 605.707 Software Patterns or equivalent experience is recommended.

Weimer
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.

Prerequisite: 605.782 or equivalent servlet and JSP experience.

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 from the instructor.

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 and permission of a faculty mentor, the student’s academic adviser, and the program chair.
Electrical and Computer Engineering

Electrical and computer engineering (formerly electrical engineering) is concerned with the use of electrical phenomena for communication, computation, information transformation, measurement, and control. Within these broad categories there exist application areas affecting nearly every facet of society. Electrical 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 Hopkins program lies in the active involvement of the faculty in 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 (M.S.) degree is offered through the part-time programs and is administered by a program committee. The M.S. 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. All courses are offered in evening hours at the Applied Physics Laboratory and at the Dorsey Center and Montgomery County Campus. The faculty are drawn from the technical staff of the Applied Physics Laboratory, from government and local industry, and from the full-time faculty of the Department of Electrical and Computer Engineering.

The areas of interest within the M.S. program span a broad spectrum of specialties. Courses are offered within the general areas of telecommunications, computer engineering, RF and microwave engineering, optical engineering, electronics and the solid state, signal processing, and systems and control.

The Master of Science in Engineering (M.S.E.) 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 M.S. program, and interactions are possible. The M.S.E. program provides graduate education in the context of an academic department. The aim is to provide master’s level work in closer contact with full-time faculty and Ph.D. candidates than is the case in the M.S. program. The faculty are drawn primarily from the Department of Electrical and Computer Engineering, but also from the technical staff of the Applied Physics Laboratory. Admission and graduation requirements are similar to those of the M.S. program, and interactions are possible. The M.S.E. program provides graduate education in the context of an academic department. The aim is to provide master’s level work in closer contact with full-time faculty and Ph.D. candidates than is the case in the M.S. program. The faculty are 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 M.S.E. program, including the catalog and admission materials, may be obtained from the Department of Electrical and Computer Engineering.

Program Committee

Dexter G. Smith, Program Chair
Principal Professional Staff
Applied Physics Laboratory

Brian K Jennison, Program Vice Chair
Senior Professional Staff
Applied Physics Laboratory

Charles Alexander
Senior Electrical Engineer
Department of Defense

Robert S. Bokulic
Principal Professional Staff
Applied Physics Laboratory

Ralph Etienne-Cummings
Associate Professor, Electrical and Computer Engineering
Whiting School of Engineering

Andrew D. Goldfinger
Principal Professional Staff
Applied Physics Laboratory

Daniel G. Jablonski
Principal Professional Staff
Applied Physics Laboratory

Richard I. Joseph
Professor, Electrical and Computer Engineering
Whiting School of Engineering

Jin U. Kang
Professor, Electrical and Computer Engineering
Whiting School of Engineering

John E. Penn
Senior Professional Staff
Applied Physics Laboratory

Michael E. Thomas
Principal Professional Staff
Applied Physics Laboratory

Douglas S. Wenstrand
Senior 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)-accredited electrical engineering program and (2) compiled an average of B (3.0 on a 4.0 scale) or above for all courses in mathematics, engineering, and the physical sciences. Applicants who majored in a related science or engineering field may also be accepted as candidates, provided their background is judged by the admissions committee to be equivalent to that stated above.
Graduate Programs
Electrical and Computer Engineering

**Telecommunications Option**
Electrical and computer engineering students who select the telecommunications option 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 courses. Of the maximum of three electives, at least two must be from the computer science networking option courses. See the Telecommunications and Networking Option page for a complete description of the telecommunications and networking option and the courses that apply.

**Photonics Option**
The M.S. in Electrical and Computer Engineering degree may be attained with a special option in photonics. This option will be noted on the student's transcript. The photonics option comprises a required core of three optics courses (525.413, 525.425, and 525.491), combined with three additional optics courses selected from the list below (“Photonics”). The four courses needed to complete the degree may be any courses approved by the adviser, selected so as to fulfill the general requirements for the M.S. described below. Applicants for the M.S. who desire to participate in the photonics option should so note on their application form.

**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 A or B.

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 adviser 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.

**Course Requirements**
Each degree candidate for the M.S. is assigned an adviser. Attainment of the degree requires completion of 10 one-term courses, specifically approved by the adviser, at least seven of which must be in electrical and computer engineering. All courses must be numbered at or above the 400-level. At least four of the 10 required courses must be at the 700-level or above. At most, one course with a grade of C may be used and no course with a grade lower than C. The electrical and computer engineering courses may be selected from among those offered through the M.S. degree program, distinguished by the course prefix 525, and listed below, or from among courses offered in the M.S.E. program of the Department of Electrical and Computer Engineering. These latter are distinguished by the prefix 520, and are listed in the Arts and Sciences/Engineering Undergraduate and Graduate Programs Catalog. Limited opportunity is available for replacement of course work by appropriate project work (see the courses 525.801 and 525.802 below).

At most, three of the 10 courses required for the M.S. degree may be selected with adviser approval from outside electrical and computer engineering. Students in the telecommunications and networking option must select at least two from the computer science networking electives. Although most students who desire an elective course select from among the offerings of the applied mathematics, applied physics, and computer science sections of this catalog, advisers have broad flexibility to approve other suitable courses in science or engineering. (Note that the courses 615.441 Mathematical Methods for Physics and Engineering, 615.442 Electromagnetics, 615.780 Optical Detectors and Applications, and 625.743 Stochastic Optimization and Control are treated as electrical and computer engineering courses rather than as electives).

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.

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Electrical and Computer Engineering

Graduate Programs

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
525.795 Advanced Communications Laboratory

Note: Computer science course electives accepted for the telecommunications and networking option are listed on the Telecommunications and Networking page.

II. Computer Engineering
525.411 Theory of Digital Systems
525.412 Computer Architecture
525.415 Microprocessor Systems
525.417 Computer-Aided Engineering of Digital Systems
525.434 High Speed Digital Design and Signal Integrity
525.441 Computer and Data Communication Networks I
525.442 VHDL/FPGA Microprocessor Design
525.712 Advanced Computer Architecture
525.719 Parallel Processing Systems
525.723 Computer and Data Communication Networks II
525.739 Computer Systems Performance Analysis
525.778 Design for Reliability, Testability, and Quality Assurance

III. RF and Microwave Engineering
525.418 Antenna Systems
525.420 Electromagnetic Transmission Systems
525.423 Principles of Microwave Circuits
525.445 Modern Navigation Systems
525.448 Introduction to Radar Systems
525.484 Microwave Systems and Components
525.738 Advanced Antenna Systems
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
615.442 Electromagnetics

IV. Photonics
525.413 Fourier Techniques in Optics
525.425 Laser Fundamentals
525.436 Optics and Photonics Laboratory
525.491 Fundamentals of Photonics
525.738 Design for Reliability, Testability, and Quality Assurance
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.

Electives appropriate to the Photonics Option:
615.471 Principles of Optics
615.472 Optical Remote Sensing
615.751 Modern Optics
615.752 Statistical 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.

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
525.429 Theory and Design of Active Analog Filters
525.432 Analog Electronic Circuit Design II
525.705 Micropower VLSI System Design
525.713 Micropower Integrated Circuit Design
525.725 Power Electronics
525.794 Advanced Topics in VLSI Technology

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
525.446 DSP Hardware Lab
525.467 Applied Bayesian and Entropic Methods
525.718 Multi-Rate Digital Signal Processing
525.721 Advanced Digital Signal Processing
525.724 Introduction to Pattern Recognition
## Electrical and Computer Engineering

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### VII. Systems and Control

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## 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.

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Andreou, Etienne-Cummings

### 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.

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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.

**Prerequisite:** An undergraduate degree in a scientific or engineering area, including familiarity with computer-aided design and engineering analysis methods for electronic circuits and systems.

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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.

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Blodgett, Harshbarger

### 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.

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Palumbo

### 525.411 Theory of Digital Systems

This course introduces the student to a very popular microcontroller, the CYPRESS PSoC (System on a Chip). The Cypress Design software EXPRESS and DESIGNER are described and used to design various applications. Furthermore, the student is introduced, to a lesser extent, to other microcontrollers, such as the Basic Stamp, the ATMEL family, and PicMICRO. A new and interesting language called ARDUINO is described and is used for various applications with the ATMEGA168. Finally, the student is introduced to the ALTERA Quartus software and is assigned the design of a simple processor, the NIOS, that is later on implemented on
an ALTERA FPGA board. PSoC and ALTERA boards are assigned to the student.

Prerequisite: An undergraduate degree in electrical engineering. Knowledge of basic digital design.

**525.412 Computer Architecture**

This course covers organization, structure, and design of computers, starting with a review of the original Von Neumann machine. Major architectural improvements since 1950 are reviewed, and the contemporary view of multilevel, virtual machines is introduced. Topics include instruction set design including RISC, addressing, interrupt and trap handling, stacks, data paths control, horizontal and vertical microprogramming, busses, paging, segmentation, and cache. Mapping of twos complement arithmetic onto register level hardware, including simple control units for Booth’s algorithm and non-restoring division, is also covered.

Prerequisite: A senior-level course in digital design.

**525.413 Fourier Techniques in Optics**

In this course, the study of optics is presented from a perspective which 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.

**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.

**525.415 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 which 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.

Prerequisites: Some experience in designing and building digital electronic systems and 525.411 Theory of Digital Systems or equivalent knowledge.

**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.

**525.417 Computer-Aided Engineering of Digital Systems**

This course introduces design automation techniques for digital hardware designers. Topics include schematic capture, hierarchical design, simulation models, logic and fault simulation, testability analysis, programmable logic design and automatic test equipment. The students work with computer-aided engineering software in the lab to design digital subsystems. This course is intended for students without previous computer-aided engineering experience.

Prerequisite: 525.411 Theory of Digital Systems or the equivalent.

**525.418 Antenna Systems**

This course develops fundamental antenna concepts and uses them to analyze basic antenna systems. Physical as well as electrical characteristics are considered for a variety of applications. Examples of actual systems are presented and recent advances discussed. Topics include physical principles of radiation and dipole and loop polarization. Basic antenna concepts include wire radiators, linear and planar arrays, horns, reflecting and nonreflecting apertures, lenses, broad-band systems, printed circuit antennas, and antenna measurements.

Prerequisite: A course in microwave engineering, such as 525.423 Principles of Microwave Circuits or 525.420 Electromagnetic Transmission Systems.

**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.

**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.

**Prerequisite:** An undergraduate degree in electrical engineering or equivalent.

**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.

**Prerequisite:** An undergraduate degree in electrical engineering or equivalent, or, in exceptional cases, upper-division status in an undergraduate electrical engineering degree program.

**Note:** Interested students should note the availability of the elective course 615.764 Solid State Materials and Devices Laboratory.

**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.

**Prerequisite:** 525.421 Introduction to Electronics and the Solid State I or approval of the instructor.

**Note:** Interested students should note the availability of the elective course 615.764 Solid State Materials and Devices Laboratory.

**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 are introduced. Circuits are physically designed using microstrip concepts, taking into consideration materials properties, connectors, and other components.

**Abita, Harvey**

**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.

**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:** An undergraduate course in mathematics.

**Thomas**

**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.
**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: 525.411 Theory of Digital Systems or equivalent background in digital design.*

**Martin**

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**525.429 Theory and Design of Active Analog Filters**
Analog filters play an important role in numerous electronic systems. This course introduces the concepts of analog filters such as basic filter functions, transfer functions, response and phase shift, filter order, log scales, filter types, filter approximations, principles of op amps. As well as, differences between analog and digital filters. The student will be exposed to a number of freeware filter design programs and will be asked to use these programs to demonstrate knowledge gained throughout the course.

*Prerequisite: An undergraduate degree in electrical engineering and basic knowledge of the theory of electronic circuits.*

**Veronis**

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**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.*

**Fry**

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**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 course work. Problem exercises and a term project require computer use.

*Prerequisite: 525.427 Digital Signal Processing. Some knowledge of probability helpful.*

**Costabile**

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**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 and sensor conditioning nonlinear transfer functions and analog computation, and power control.

*Prerequisite: 525.424 Analog Electronic Circuit Design I or permission of the instructor.*

**Darlington**

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**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. Some of the topics discussed are 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, gigabit ethernet specification, and short transmission line model.

*Prerequisite: Thorough knowledge of digital design and basic circuit theory.*

**Veronis**

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**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, LED's), phase and amplitude modulators, lidar, fiber-optic communications, 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.*

**Sova, Terry**

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**525.437 Telecommunications Signal Processing**
This course integrates and extends the fundamental concepts in communications and signal processing to telecommunications signal processing (TSP). Analysis and design methods are developed and compared for several theoretical and practical TSP systems. Topics include data and voice communications, echo cancellers and suppressors, channel filter banks,
adaptive arrays, transmultiplexers, delta/sigma modulation, and speech compression. Students examine industrial applications, and they gain experience from practical examples and an assigned class project.

**Prerequisite:** 525.416 Communication Systems Engineering or equivalent.

525.438  **Introduction to Wireless Technology**

This course introduces students to the modern technology involved with commercial wireless communications systems such as digital cellular, personal communications systems (PCS), wireless local area networks (WLAN), code division multiple access (CDMA) systems, and other topics. Various multiple access methods and signal formats are considered. Hardware implementations of system components are presented and analyzed. Modulation and demodulation architectures are introduced and modeled using PC based tools.

**Prerequisites:** An undergraduate degree in electrical engineering or the equivalent. Experience with Matlab and Simulink will be helpful.

Roddewig

525.439  **Introduction to High-Speed Networks**

This course provides a broad introduction to the basic concepts of high-speed wide area networks, such as frame relay, FDDI and FDDI-II, DQDB, SMDS, ATM, fast Ethernet, and 100VG-AnyLAN. The concepts and architecture of SONET/SDH are also reviewed. The principal parameters, formats, protocol layers, physical layers, and interfaces of these network architectures are discussed. The course begins by reviewing circuit switching, packet switching, and cell switching concepts, as well as ISDN and X.25. Frame relay protocol, traffic rate management, and network congestion management are also covered. High speed MANs, such as FDDI, FDDI-II, and DQDB are introduced and their operations are described. SMDS service is reviewed and compared with frame relay service. Key features of ATM are discussed, such as cell formats, asynchronous multiplexing to mix different traffic types, congestion control, and traffic policing. Finally, the course explores emerging high speed LANs and virtual LANs.

**Prerequisite:** A basic course in data communications, such as 525.441 Computer and Data Communication Networks I, or an introductory course in local area networks.

Nasrabadi

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, or equivalent.

Nasrabadi

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 multiservice 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.

Hanson, Nasrabadi

525.442  **VHDL/FPGA Microprocessor Design**

This lab oriented course covers the design of digital systems using VHSIC 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:** 525.415 Microprocessor Systems is suggested but not required, as well as an understanding of digital logic fundamentals.

Haber, Meitzler, Wenstrand

525.444  **Introduction to ATM Networks and Video Applications**

This course provides an introduction to the basic concepts and techniques used in asynchronous transfer mode (ATM) communications networks. The course reviews circuit and packet switching techniques, local area networks (LAN), N-ISDN, B-ISDN, and high speed local and metropolitan area networks (MAN). Other topics covered include introduction to ATM standards and protocols; ATM layer, ATM adaptation layer, and physical layer; ATM switching architectures; call and connection control, traffic control, and network management; packet video, including characterization of video sources, signal modeling for prediction of statistical multiplexing, packet loss protection and recovery, and layered video coding with prioritized packets.

**Prerequisite:** 525.441 Computer and Data Communication Networks I or 605.471 Principles of Data Communication Networks.

Nasrabadi
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.

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.

Prerequisite: 525.427 Digital Signal Processing and C programming experience.

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 be discussed.

Prerequisite: 525.414, Probability and Stochastic Processes for Engineers or equivalent. A working knowledge of Fourier transforms, linear systems including discrete time systems and concepts, and electromagnetics. Familiarity with Matlab.

Farthing

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.

525.467 Applied Bayesian and Entropic Methods
This course introduces Bayesian and entropic methods and their signal processing applications in the treatment of random phenomena. The common logical foundations of the two classes of methods are discussed. Probability represents degree of belief on the part of a decision maker, while entropy indicates the degree of utility of questions posable by an observer. Practical examples and applications illustrating these concepts are given in conjunction with related Matlab homework assignments. The course objective is to convey a logical methodology of problem solving applicable to a wide domain of technical and non-technical disciplines.

Fry

525.484 Microwave Systems and Components
This course deals with the practical aspects of microwave systems and components. An overview of communication systems is followed by an introduction to radar systems and electronic systems operating in heavily interfering environments. The majority of the course treats the linear and nonlinear characteristics of individual components and their relation to system performance. Amplifiers, mixers, filters, and frequency sources are studied, as well as their interactions in cascade. Performance specification and testing are considered, using actual receiver designs as examples. Some homework problems may require use of computer-aided design software provided at the Dorsey Center.

Prerequisite: An undergraduate degree in electrical engineering or equivalent.

McClaning, Thompson

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 photon sources and detectors, nonlinear optics, electro-optics and acousto-optics.

Prerequisite: An undergraduate course in electromagnetic theory.

Sova

525.705 Micropower VLSI System Design
This course considers micropower circuits with emphasis at the level of system integration. Topics discussed include mixed digital and analog/digital components on a single chip, A/D and D/A converters, design for testability, and fault tolerance. The course requires a final project involving a small system
that is fabricated through MOSIS, as well as laboratory experiments on previously fabricated circuits and small systems.  

**Prerequisite:** 525.713 Micropower Integrated Circuit Design.

### 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 Linear Algebra; in probability, such as 525.414 Probability and Stochastic Processes for Engineers, and indigital communications, such as 525.416 Communication Systems Engineering.

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**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.

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**Cameron**

### 525.713 Micropower Integrated Circuit Design

This course focuses on devices and circuit techniques for micropower applications, such as biomedical instrumentation, implantable devices, and space applications. Both voltage and current mode techniques are introduced for the implementation of analog signal processing functions. The design of precision micropower circuits in the standard CMOS process is stressed. Design tools for layout, simulation, and verification are also introduced. A final project involves the design of a small circuit that will be fabricated through MOSIS.  

**Prerequisites:** Undergraduate courses in systems and electronics.

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**Martin**

### 525.718 Multi-Rate Digital Signal Processing

Multi-rate signal processing techniques find applications in many areas including speech and image compression, digital audio, and adaptive signal processing. This course provides an in-depth treatment of both the theoretical and practical aspects of multi-rate signal processing. The course begins with a review of discrete-time systems and the design of digital filters. Additional topics discussed are: polyphase realizations of discrete systems; multistage filter design; and the design of filter banks, including perfect reconstruction, alias-free, and quadrature mirror filter types. Each student is required to complete a comprehensive individual project on some aspect of multi-rate signal processing.  

**Prerequisites:** 525.427 Digital Signal Processing or equivalent and working knowledge of Matlab.

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**Jennison**

### 525.719 Parallel Processing Systems

This course introduces parallel hardware/software computing structures. Topics include pipelining and vector machines, structures and algorithms for array processors, multiprocessor architectures and control, data flow machines, and VLSI parallel computing structures.  

**Prerequisite:** 525.412 Computer Architecture or equivalent undergraduate background.

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**Darling, Pascale**

### 525.721 Advanced Digital Signal Processing

The fundamentals of discrete-time statistical signal processing are presented in this course. Topics include optimal linear filter theory, classical and modern spectrum analysis, adaptive filtering, and the singular value decomposition and its application to least squares problems. Basic concepts of super-resolution methods are described, including an introduction to array processing. Computer experiments using Matlab illustrate some of the signal processing techniques.  

**Prerequisites:** 525.414 Probability and Stochastic Processes for Engineers, 525.427 Digital Signal Processing, and the basics of linear algebra.

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**Najmi, Sadler**

### 525.722 Wireless and Mobile Cellular Communications

In this course, students examine fundamental concepts of mobile cellular communications and specifications 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.

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**Zuelsdorf**

### 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 sys-
tems, 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.

Hanson

525.724 Introduction to Pattern Recognition
Both statistical and nonstatistical methods are covered. The statistical methods are subdivided into parametric and nonparametric methods. The parametric methods are limited to the Bayes criterion. The nonparametric methods include linear, nonlinear, and piecewise linear discriminant functions, estimation of unknown density functions, and nearest neighbor classification rules. The second part of the term emphasizes unlabeled samples. While statistical methods have some utility in this area, clustering techniques are emphasized. Included in these techniques are similarity measures, hierarchical clustering, minimal spanning tree, and multidimensional scaling.

Prerequisite: 525.417 Probability and Stochastic Processes for Engineers or equivalent.

Trunk

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 verses 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 nonidealities 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 which 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

Marcus, Temkin

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.

Prerequisite: 525.414 Probability and Stochastic Processes for Engineers or equivalent.

Trunk

525.738 Advanced Antenna Systems
This course is designed to follow Antenna Systems 525.418. 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.

Prerequisite: 525.418, Antenna Systems.

Weiss

525.739 Computer Systems Performance Analysis
This course provides an overview of computer system performance analysis using experimental measurements, simulations, and modeling. Queuing models and queuing networks are used to model computer systems, analyze system performance, and establish performance bounds. Specific computer subsystems are modeled, including memory, I/O and processors. Limitations of queuing models are discussed. Markov models are described, as well as experimental performance techniques such as benchmarking and performance monitoring.

Prerequisites: 525.412 Computer Architecture or consent of instructor.

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.

Prerequisite: 525.414 Probability and Stochastic Processes for Engineers and 525.466 Linear System Theory or equivalents.

Levy

525.746 Image Engineering
Optical, photographic, analog, and digital image processing are highlighted. Topics include image input, output, and processing devices; visual perception; video systems; and fundamentals of digital image enhancement, processing, and understanding. Coding, filtering, transform, restoration, and segmentation techniques are covered, as well as applications to remote sensing and biomedical problems.
Electrical and Computer Engineering

Prerequisites: 525.427 Digital Signal Processing or equivalent and knowledge of linear systems.

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, recognition, speech synthesis, and speaker identification are discussed. Application areas include telecommunication, 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 helpful.

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.

525.753 Laser Systems and Applications
This course provides a comprehensive treatment of the generation of laser light, 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.

Prerequisite: 525.425 Laser Fundamentals.

525.754 Wireless Communication Circuits I
In this course, students examine modulator and demodulator circuits used in communication and radar systems. A combination of lectures and laboratory experiments address 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.

Prerequisite: 525.416 Communication Systems Engineering or 525.484 Microwave Systems and Components or permission of the instructor.

525.755 Wireless Communication Circuits II
This is a lab-based course in which students will design, build, and test a communications-related system. The nature and extent of the project will be negotiated between the student and instructors during the first week of class. Candidate projects include spread spectrum systems, PSK modulators and demodulators, m-ary FSK modulators and demodulators, and others. Students will be expected to procure any unusual components they require for their project (i.e., specialized ICs, unusual development systems, etc.).

Prerequisites: 525.754 Wireless Communication Circuits I or permission of the instructors. Students are required to assemble circuitry outside the course hours, thus reserving class time for debugging, testing, and instructor interaction.

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.

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 many of the capabilities of these standards are still being developed, and have not been integrated into computer and communication systems, the study of the component technologies will provide guidelines for evaluation and selection when the standards are approved.
 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. A mini-project is required. 

**Prerequisite:** 525.427 Digital Signal Processing.

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**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 U.S. 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 advanced intelligence, wireless network mobility, and long distance capabilities are shown to provide many new combinations of wired and wireless services to users.

**Prerequisite:** 525.408 Digital Telephony, or 525.416 Communication Systems Engineering, or permission of instructor.

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**525.762 Signal Processing with Wavelets**

This course presents the fundamentals of wavelets as a signal processing tool. Topics include continuous and discrete-time wavelets, time-frequency transient analysis, wavelet bases, wavelet packets, and approximations with wavelets. Applications include signal and image denoising (filtering), and compression. Computer experiments using Matlab illustrate the techniques studied.

**Prerequisite:** 525.427, Digital Signal Processing and the basics of linear systems.

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**525.763 Applied Nonlinear Systems**


**Prerequisite:** 525.409 Continuous Control Systems or equivalent.

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**525.769 Digital and Sampled-Data Control**

This course covers analysis and design of control systems that include both continuous-time and discrete-time elements such as samplers, A/D and D/A converters, and digital computers. Topics include sampling, difference equations, z- and w-transforms, block diagram analysis, system stability, classical design by root-locus and frequency response methods, state-space analysis and design, system identification, and optimal estimation and control. Application of theory to practical analysis and design problems is emphasized.

**Prerequisite:** Familiarity with Laplace transforms, linear systems, and techniques for analyzing and designing continuous-time control systems is assumed.

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**525.770 Intelligent Algorithms**

This course investigates several techniques commonly referred to as intelligent algorithms, and takes a pragmatic engineering approach to the design, analysis, evaluation, and implementation of intelligent systems. Fuzzy systems concepts are discussed, and several engineering applications are presented, including fuzzy control and fuzzy estimation and prediction. The role of Expert (rule-based) Systems is discussed within the context of fuzzy systems. In addition, neural networks and genetic algorithms are introduced, and their relationships to fuzzy systems are highlighted. A fuzzy systems computer project must be selected and implemented by the student. Student familiarity of system-theoretic concepts is desirable.

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**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 are described which contribute to the various types of propagation conditions in the troposphere.

**Prerequisite:** An undergraduate degree in electrical engineering or equivalent.

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**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.

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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.
Prerequisite: 525.423 Principles of Microwave Circuits or equivalent.
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.
Prerequisite: 525.774 RF and Microwave Circuits I.
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.
Benedict

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.
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 space 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.
Prerequisites: 525.411 Theory of Digital Systems or equivalent.
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.
Prerequisites: 525.774, RF and Microwave Circuits I or equivalent.
Meitzler, Penn

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 investigation 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.
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, cryptograph, and error correction systems are explored. The mathematics of pseudo-random sequences used as spreading codes are compared with the mathematics of complex numbers with which students are already familiar.

**Prerequisite**: 525.416 Communication Systems Engineering.

Jablonski

**525.786 Model Building for Dynamic Systems**

The course presents the theory and practice of system identification, which is the process of estimating statistical system models from data. State-space methods are used in discussing both adaptive filtering and control, where the system model must be estimated on-line, and off-line model building, for simulation development and validation, and test and evaluation. Practical implementations are covered along with example applications to real-world problems. Methods include nonlinear extended Kalman, residual analysis, and multiple model adaptive filters; the eigensystem realization algorithm; canonical variate analysis; and subspace model identification, as well as simultaneous perturbation stochastic approximation and maximum likelihood, prediction error minimization, and model structure estimation methods. Applications include adaptive control of a farm vehicle, urban traffic control, missile inertial guidance modeling, and GPS receiver modeling.

**Prerequisite**: 525.745 Applied Kalman Filtering or equivalent.

Levy

**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.

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 CADE tools. There is not a project, 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.

Dawson

**525.789 Digital Satellite Communications**

This course covers advanced topics in satellite communications 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 recommended.

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**: 525.775 RF and Microwave Circuits II or equivalent.

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 a fundamental 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.

### 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 trade-offs, multiplexing, and multiple access.

**Prerequisites:** 525.414 Probability and Stochastic Processes for Engineers; 525.416 Communication Systems Engineering

### 525.794 Advanced Topics in VLSI Technology

This course will concentrate on advanced concepts in VLSI design. Additional emphasis will be put on system architecture, circuit analysis, device modeling, simulation, and optimization. Topics include advanced logic techniques, parasitic circuit elements, advanced simulation techniques, temperature effects, and circuit and device performance limits. Additional topics may include low-power/low-energy design techniques, performance limits, radiation effects and cryogenic VLSI.

**Prerequisite:** 525.428 Introduction to Digital CMOS VLSI, or equivalent background in digital design.

### 525.795 Advanced Communications Laboratory

This course offers the student an opportunity for hands-on experience with advanced digital signal processing techniques used in modern mobile communications systems. Topics include automatic gain control, synchronization and carrier phase estimation, channel and source coding, and frequency-selective channel equalization. Assignments will focus primarily on Matlab programming of various receiver signal processing methods.

**Prerequisites:** 525.427, 525.414, and 525.416 (or equivalent advanced undergraduate/first year graduate courses in Digital Signal Processing, Stochastic Processes, and Communication Systems). Basic concepts of communication and linear systems, transforms.

### 525.796 Introduction to High-Speed Electronics and Optoelectronics

This course provides the student with the fundamentals 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.

**Prerequisite:** Undergraduate courses in circuits and systems.

### 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.

### 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 committee chair. Such arrangements are made relatively infrequently. This course number should be used for the first registration of a student in any special project.

**Note:** To be assured consideration for any term, project proposals should reach the program chair by the end of the mail-in registration period.

### 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.)

**Note:** To be assured consideration for any term, project proposals should reach the program chair by the end of the mail-in registration period.
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. 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
- 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 and Applied Science Programs for Professionals Whiting School of Engineering

William P. Ball
Professor, Geography and Environmental Engineering Whiting School of Engineering

John J. Boland
Professor Emeritus, Geography and Environmental Engineering Whiting School of Engineering

Edward J. Bouwer
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J. Hugh Ellis
Department Chair and Professor, Civil Engineering Whiting School of Engineering

Charles R. O’Melia
Abel Wolman Professor Emeritus, Geography and Environmental Engineering Whiting School of Engineering

Peter R. Wilcock
Professor and Departmental Associate Chair, Geography and Environmental Engineering Whiting School of Engineering

Program Advisory Board

An external Advisory Board provides oversight, vision, input, and perspective from the professional, technical, and business communities. The Board consists of distinguished representatives from professional environmental organizations, state and federal agencies, prominent environmental consulting firms/industry, part-time faculty, and part-time students. The Advisory Board is co-chaired by William C. Anderson, executive director, Council of Engineering and Scientific Specialty Boards, and George A. Frigon, president of Newfields Corporation. Please see the Appendix for the list of the Advisory Board members and their affiliations.

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 Research Council, U.S. Department of Defense, U.S. Department of Agriculture, National Institute of Standards and Technology, U.S. Army Corps of Engineers and many leading environmental consulting companies such as Environmental Resource Management, EA Engineering, Science and Technology, Bechtel Corporation, CH2M Hill, and Northrop Grumman. Please see the Appendix for the list of active faculty members and their affiliations.
Online Options
The Master of Science in Environmental Planning and Management is available fully online. All environmental engineering students may register for online courses to meet degree requirements.

Degrees and Certificates
The program offers professional non-thesis degrees in the following three areas of study and their corresponding Advanced Certificate for Post-Master’s Study as well as Graduate Certificates:

- Master of Environmental Engineering
- Master of Science in Environmental Engineering and Science
- Master of Science in Environmental Planning and Management
- Advanced Certificate for Post-Master’s Study
- Graduate Certificate

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 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).

Course Requirements
Attainment of the Master of Environmental Engineering degree requires completion of 10 one-term courses, including at least any four courses at the 575.7xx level or above, within five years.

Up to five additional 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, Master of Science in Environmental Planning and Management).

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 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 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 any four courses at the 575.7xx level or above, within five years.

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 additional 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, Master of Science in Environmental Planning and Management).

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 disciplines from a four-year 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 disciplines.
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 any four courses at the 575.7xx level or above, within five years.

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 additional 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, Master of Science in Environmental Planning and Management).

Up to two elective courses, subject to prerequisite restrictions, compatibility in the number of credit hours, and adviser approval may be taken from select related courses offered through all different schools of the Johns Hopkins University.

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 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. All grades for the six courses must be A or B.

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 adviser 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.

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.

The certificate consists of six courses. All grades for the six courses must be A or B. 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 adviser with whom he or she jointly designs a program tailored to individual educational goal.

Students must complete the Graduate Certificate within three years of the first enrollment in the program.

Program Plan
Each student admitted to a degree or certificate program is assigned an academic adviser with whom he or she jointly designs a program plan tailored to individual educational objectives and the degree provisions. After admission to the degree program, students must submit an initial program plan indicating the courses they wish to take to fulfill the degree requirements. This plan, and subsequent changes to it, must be approved by the student’s adviser.

Special Student
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 D.C. 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**
- 575.404 Principles of Environmental Engineering
- 575.405* Principles of Water and Wastewater Treatment
- 575.406 Water Supply and Wastewater Collection
- 575.407 Radioactive Waste Management
- 575.420 Solid Waste Engineering and Management
- 575.423 Industrial Processes and Pollution Prevention
- 575.703 Environmental Biotechnology
- 575.706 Biological Processes for Water and Wastewater Treatment
- 575.715 Subsurface Fate and Contaminant Transport
- 575.721 Air Quality Control Technologies
- 575.742 Hazardous Waste Engineering and Management
- 575.745 Physical and Chemical Processes for Water and Wastewater Treatment
- 575.746 Water and Wastewater Treatment Plant Design
- 575.801 Independent Project in Environmental Engineering, Science and Management

*Offered in an online format as well.

**Master of Science in Environmental Engineering and Science**
- 575.401* Fluid Mechanics
- 575.415* Ecology
- 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.
- 575.710 Financing Environmental Projects
- 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
- 575.727 Environmental Monitoring and Sampling
- 575.728 Sediment Transport and River Mechanics
- 575.730 Geomorphic and Ecologic Foundations of Stream Restoration
- 575.744 Environmental Organic Chemistry
- 575.801 Independent Project in Environmental Engineering, Science and Management

*Offered in an online format as well.

**Master of Science in Environmental Planning and Management**
- 575.408* Optimization Methods for Public Decision Making
- 575.411* Economic Foundations for Public Decision Making
- 575.419 Principles of Risk Assessment and Management
- 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
- 575.707* Environmental Compliance Management
- 575.710 Financing Environmental Projects
- 575.711 Climate Change and Global Environmental Sustainability
- 575.714* Water Resources Management
- 575.720 Air Resources Modeling and Management
- 575.723 Sustainable Development and Next Generation Buildings
- 575.731* Water Resource Planning
- 575.733 Energy Planning and the Environment
- 575.741 Seminar in National Water Resources Planning
- 575.747* Environmental Project Management
- 575.759* Environmental Policy Analysis
- 575.801 Independent Project in Environmental Engineering, Science and Management

*Offered in an online format as well.

**Cross-listed Courses from the Bloomberg School of Public Health Departments of Environmental Health Sciences and Epidemiology**
- 180.601 Environmental Health
- 180.611 The Global Environment and Public Health
- 180.630 Public Health Aspects of Environmental Law
- 182.625 Principles of Industrial Hygiene
- 182.626 Tropical Environmental Health
- 183.639 Food- and Water-borne Diseases
- 183.641 The Health Effects of Indoor and Outdoor Air Pollution
- 186.601 Introduction to Radiation Health Sciences
- 187.610 Principles of Toxicology
- 188.680 Fundamentals of Occupational Health
- 188.681 Occupational Health
- 188.687 Occupational Health in Developing Countries
- 340.601 Principles of Epidemiology

*Offered in an online format as well.
**Course Descriptions**

**575.401 Fluid Mechanics**
The 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.

**575.404 Principles of Environmental Engineering**
This course provides knowledge of environmental elements with insight into quantitative analysis and design 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, 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.

**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.

**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 nucleides, 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.

**575.408 Optimization Methods for Public Decision Making**
This course is an introduction to applied operations research, that is, the development of optimization and simulation mod-
els intended to help people make decisions involving complex problems. The concepts and tools that we work with include linear and nonlinear optimization, dynamic programming, multiobjective optimization, integer programming, stochastic programming and Markov decision processes. The material is presented in an environmental engineering–relevant context, with practical engineering problems frequently serving as both the motivation and the means through which the concepts of the course are taught. Such problems span a diverse array of timely issues involving water and air pollution control, logistical planning, and resource allocation.

Williams

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.

Boland, Cantor, Nieberding

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.

Hillgartner

575.419 Principles of 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.

Dellarco

575.420 Solid Waste Engineering and Management

This course covers advanced 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; 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.

Alavi

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 economical 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, reuse and recycling will be addressed to selected industries such as textiles, electroplating, pulp and paper, and petroleum refining.

Engel-Cox

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 waterbearing 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.

Taylor
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 which are likely to arise in the engineering profession and introduces them to the complexities and vagaries of the legal profession.  
Leiman

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 media 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.  
Root, Stoddard

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.  
Wilson

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 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.  
Toussaint

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.  
Roper

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.  
Gilbert

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 which may be applicable to environmental biotechnology. 

Wilson-Durant

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.
Lasat, Wilson-Durant

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 which are inherently noisy. Statistically designed experimental 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. 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.
Bodt

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. 
Prerequisites: 575.405 Principles of Water and Wastewater Treatment.
Curley

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; institutional objectives including economic competitiveness.
Weiss

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 2-D flow modeling, and applications to channel design and stability.
Prerequisites: Fluid Mechanics or an equivalent course in fluid flow or hydraulics.
Riegel

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 guaranties; 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 financing combining many of the elements introduced during the course are presented and analyzed.
Hudson
575.711 Climate Change and Global Environmental Sustainability

This is a multidisciplinary course that involves the application of engineering and policy to address issues related to climate change and global environmental sustainability. The course will be taught in four modules that pertain to the physical environment, anthropological perspectives, climate change, and an array of other global sustainability topics. A discussion of earth origins, oceans and the hydrologic cycle, the atmosphere and the biosphere will lay the foundation for advanced investigations of global environmental inter-relationships and interactions between humans on a regional scale and their resultant global impact. An assessment of health and global environmental change; people, cultures, and environmental sustainability; and environmental analysis, design, and modeling will explore the relationships between the global environment and the human race with focal areas on human health, causes and consequences of environmental degradation, environmental management and ethics, and environmental modeling and assessment. A climate change module will quantitatively address climate change science; present evidence of climate change observations and review models and predictions of potential physical, ecological, and anthropological impacts; summarize past and present local, state, federal, and international policy and legislation; and promote an array of technological, economic, political, and consumer driven solutions. Additional specific global environmental sustainability topics will include water resource policy, global energy demand, transportation engineering, urban and regional planning, sustainable agriculture, conservation biology, environmental cleanup and restoration, and green technologies. Students will be required to critically review current journal articles and both science and policy weighted presentations, attend field trips, lead class discussion sections, actively participate in a sustainability workshop, and complete a term project in addition to fulfilling homework, attendance, reading, and class participation expectations.

Robert

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 quadrat 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 to regional and local sites.

Prerequisite: 575.415 Ecology.

Hilgarten

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.

Summers, Cardwell

575.715 Subsurface Fate and Contaminant Transport

The course covers the nature and sources of chemicals 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 contaminant transport. 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.

Barranco

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 centers around the tidal waters of the Chesapeake Bay and its tributaries while also including relationships with the surrounding watershed, atmosphere, and ocean and 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.

Brush

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.

Raffensperger
575.720  **Air Resources Modeling and Management**

Topics covered in this course include an overview of atmospheric motion to give students a sense of how air pollutant transport and transformation is modeled; regulatory considerations in air pollution control related to model selection and use; system analytic approaches for developing air pollution control strategies; a brief overview of air pollution control technology; the state of air pollution in Maryland and the United States; and a detailed look at air pollution data and related information—what exists, how can data be accessed and processed, and which organizations collect and manage data. Specific air pollution problems addressed in the course include those involving tropospheric ozone, stratospheric ozone, acid rain, carbon monoxide, nitrogen oxides, and particulate matter.

Ellis

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.

Roberts

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—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 practic-
es 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.

Roper

575.727  **Environmental Monitoring and Sampling**

The course examines in detail the principles and methods for monitoring and discrete sampling of environmental media, including surface water, groundwater, soil, air, solid wastes, and tissues within the context of regulatory compliance. Basic health and safety issues and Data Quality Objectives will be covered initially. Sampling design covers basic statistical concepts including data variability and detection of significant differences among sample sets. Regulatory perspectives reviews requirements of the major statutes governing sampling of various media, including the Clean Water Act, Clean Air Act, CERCLA, and RCRA. Sampling methods surveys current methods for discrete sampling and automated data acquisition for each medium. Chemical and biological analysis reviews laboratory methods for analyzing samples. Data presentation and interpretation covers data management methods to support decision making. The course includes field trips and off-campus lectures and/or demonstrations at laboratories.

Stoddard

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.

*Prerequisites:* Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

Wilcock
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 tradeoffs 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.

Wilcock

575.731  Water Resource 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 resources management. The course will demonstrate the process for planning a water resource project, including identifying the problems and opportunities, inventorying 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.

Kranzer

575.733  Energy Planning and the Environment

This course examines the interconnections between the environment and the ways in which energy is produced, distributed, and used. Particular attention is paid to consequences of government intervention and regulation, as well as market and regulatory economics. The purpose is to help students understand how energy industries operate, and how public policy shapes the impact that these industries have on the environment.

Prerequisite: 575.411 Economic Foundations for Public Decision Making, or an equivalent course in microeconomic theory.

Lightner

575.741  Seminar in National Water Resources Planning

This seminar addresses the theory and practice of water resources planning at all levels of government, with particular emphasis on federal-level planning and state-federal relationships. Although this is nominally an online course, it begins with a five-day residence session, conducted at the Johns Hopkins University in Baltimore. The residence session includes a series of lectures by JHU faculty and distinguished scholars from several other universities. During this session, personnel from the U.S. Army Corps of Engineers (USACE) will present a complex case study, typically an ongoing Corps feasibility study that involves significant economic, social, and environmental issues. Where feasible, part of the presentation may take place at the project site. After the residence session, students return home and begin a six-week online session. During this time, the students are expected to complete individual assignments and to collaborate in the preparation of a comprehensive planning report (comparable to feasibility reports performed by USACE) that addresses all aspects of the case study, considers and evaluates alternatives, and makes a final recommendation. These products will be reviewed and critiqued online by a panel of experienced planners.

Prerequisite: Students are expected to have successfully undertaken introductory graduate study or have equivalent work experience in the following areas (substitutions and alternative qualifications will be considered): engineering for water resources planning, economic analysis (including project evaluation), ecology, hydrology/hydraulics/climatology, and quantitative methods (including optimization methods).

Boland

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/Bloomfields site remediation processes.

Alavi

575.744  Environmental Organic Chemistry

This course focuses on examination of processes that affect the behavior and fate of anthropogenic organic contaminants in aquatic environments. Students learn to predict chemical properties influencing transfers between hydrophobic organic chemicals, air, water, sediments, and biota, based on a fundamental understanding of intermolecular interactions and thermodynamic principles. Mechanisms of important thermochemical, photochemical, and biochemical transformation reactions are also investigated, leading to development of techniques (such as structure-reactivity relationships) for assessing environmental fate or human exposure potential.

Prerequisite: Introductory organic chemistry.

Jayasundera
575.745 Physical and Chemical Processes for Water and Wastewater Treatment

In the 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.

Arora

575.746 Water and Wastewater Treatment Plant Design

This course familiarizes students with appropriate design criteria and the design process for water and wastewater treatment plants. This includes design of treatment processes, cost estimates, and a working design team under project managers. Additional course requirements include oral presentations and writing engineering reports.

Prerequisites: 575.405 Principles of Water and Wastewater Treatment and one of 575.706 Biological Processes for Water and Wastewater Treatment or 575.745 Physical and Chemical Processes for Water and Wastewater Treatment.

Arora

575.747 Environmental Project Management

This course educates students on the key elements of an integrated approach to environmental project management, an endeavor which 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 governmental environmental projects, and pollution prevention/waste minimization projects.

Toussaint

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.

Boland

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 at Johns Hopkins University. The proposal description and completed required forms must be submitted prior to registration for approval by student’s adviser and the program chair. A maximum of one independent project course may be applied toward the master’s degree or post-master’s certificate.
Information Systems and Technology

Information technology permeates all aspects of modern society. The Information Systems and Technology (IS&T) program stresses the analysis, design, development, and integration of systems that enable the effective and efficient use of information. With emphasis in computer science, networking, and technical management, the discipline employs techniques and methodologies that allow practitioners to create and manage automated systems that can be used to solve real world problems.

The Master of Science in IS&T 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 abilities to develop real world information systems. It will also appeal to technically oriented business people looking to acquire a deeper understanding of information technology in order to manage systems and resources more effectively. By providing a broad-based education in the field, the IS&T program allows students to design effective information systems, develop efficient computer and communications networks, conduct complex systems analyses, and create sophisticated decision-support systems.

Courses are offered across a wide variety of topic areas, including decision-support systems, telecommunications and networking, software engineering, database and multimedia systems, human computer interaction, distributed systems, and project management. Research and development interests of the faculty span the spectrum of information systems and technology.

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

Ralph D. Semmel, Program Chair
Principal Professional Staff
Applied Physics Laboratory

John A. Piorkowski, IS&T Coordinator
Principal Professional Staff
Applied Physics Laboratory

Eleanor Boyle Chlan
Senior Lecturer in Computer Science
Whiting School of Engineering

Admission Requirements

Applicants must meet the general requirements for admission to a graduate program outlined in the Admission Requirements section of this catalog. In addition, applicants should have completed the following:
1. One year of college mathematics
2. One year of introductory computer science including a course in Java or C++, and a course in data structures.

Applicants who have not taken the prerequisite undergraduate courses may satisfy admission requirements by completing equivalent courses with grades of A or B. In particular, those students who do not satisfy the introductory computer science requirements may take the following undergraduate courses:
605.201 Introduction to Programming Using Java
605.202 Data Structures

Course Requirements

Ten courses, approved by an adviser, must be completed within five years. At least eight courses must be from the IS&T curriculum, which includes IS&T courses, applied computer science courses, and selected systems engineering and technical management courses. Three courses must be from the same concentration area 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.

Graduate students not pursuing a master’s degree in information systems and technology should consult with their adviser to determine what courses must be successfully completed before 400- or 700-level IS&T courses may be taken. 700-level courses are open only to students who have been admitted with graduate status.

Please refer to the course schedule each term for dates, times, locations, fees, and instructors.

**Foundation Courses**
All students working toward a master’s degree in information systems and technology must take three foundation courses before taking other graduate courses:

- 605.401 Foundations of Software Engineering
- 635.411 Foundations of Networking and Telecommunications
- 635.421 Foundations of Decision Support Systems

**Foundation Course Waivers**
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 courses, and may take these courses after all remaining foundation course requirements have been satisfied.

**IS&T Courses**

- 635.411 Foundations of Networking and Telecommunications
- 635.412 Local and Wide Area Network Technologies
- 635.413 IP Networking and Applications
- 635.414 Wireless Networking
- 635.421 Foundations of Decision Support Systems
- 635.431 Information Systems Architectures and Methodologies
- 635.444 XML: Technology and Applications
- 635.476 Information Systems Security
- 635.482 Web Site Development
- 635.483 Electronic Commerce
- 635.711 Internetworking: Methods, Technologies, and Devices
- 635.721 Human–Computer Interaction
- 635.731 Distributed Architectures
- 635.792 Management of Innovation
- 635.795 Information Systems and Technology Capstone Project
- 635.801 Independent Study in Information Systems and Technology I
- 635.802 Independent Study in Information Systems and Technology II

**Undergraduate Courses**

- 605.201 Introduction to Programming Using Java
- 605.202 Data Structures

**Concentration Areas**
The IS&T concentration areas including all applicable courses in IS&T, applied computer science, systems engineering, and technical management are as follows:

**I. Information Assurance Systems**

- 605.431 Principles of Information Assurance
- 605.432 Public Key Infrastructure and Managing E-Security
- 605.433 Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms
- 605.434 WWW Security
- 605.731 Network Security
- 605.734 Information Assurance Architectures and Technologies
- 635.476 Information Systems Security

**II. Distributed Systems**

- 605.481 Distributed Development on the World Wide Web
- 605.484 Collaborative Development with Ruby on Rails
- 605.781 Distributed Objects
- 605.782 Web Application Development with Servlets and JavaServer Pages (JSP)
- 605.784 Enterprise Computing with Java
- 605.785 Web Services: Framework, Process, and Applications
- 605.786 Enterprise System Design and Implementation
- 605.787 Rich Internet Applications with Ajax
- 605.482 Web Site Development
- 605.483 Electronic Commerce
- 605.731 Distributed Architectures

**III. Knowledge Management**

- 605.441 Principles of Database Systems
- 605.445 Artificial Intelligence
- 605.741 Distributed Database Systems
- 605.743 The Semantic Web
- 605.744 Information Retrieval
- 635.444 XML: Technology and Applications

**IV. Software Systems**

- 605.401 Foundations of Software Engineering
- 605.402 Software Analysis and Design
- 605.404 Object-oriented Programming with C++
- 605.407 Agile Software Development Methods
- 605.408 Software Project Management
Course Descriptions

635.411 Foundations of Networking and Telecommunications
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.

Burbank, Gump, Romano

635.412 Local and Wide Area Network Technologies
This course provides an in-depth presentation of the fundamental technology, architecture, and protocols necessary for local- and wide-area networking. It covers network topology, transmission media, media access control, interconnection devices, and fundamental communications standards such as IEEE 802. It addresses important LAN and WAN concepts such as switching, virtual LANs, DWDM, and interconnection of different LAN and WAN technologies. It also examines typical communication protocols used in LAN and WAN systems such as Ethernet, Fibre Channel, SONET, xDSL, cable modems, and ATM/Frame Relay.

Prerequisite: 635.411 Foundations of Networking and Telecommunications.

Romano

635.413 IP Networking and Applications
This course covers the underlying networking protocols and technologies upon which the Internet and other IP-based networks are built. The TCP/IP suite, including IP, TCP, UDP, and ICMP are studied in detail. Routing protocols for IP-based networks are explored including BGP, OSPF, and IGRP; ARP, DHCP and the Domain Name Service and other important utility protocols are also discussed. A comprehensive survey is provided of the applications that are being implemented over IP-based networks, including secure electronic commerce, streaming media, Voice over IP, content distribution, and future directions. In addition to textbook assignments, students will have assigned readings and research from the web.

Prerequisite: 635.411 Foundations of Networking and Telecommunications.

Hsu, Romano

635.414 Wireless Networking
This course provides an overview of emerging and existing technologies in wireless networking from the perspectives of wireless telephony, wireless data networking, and sensor networking. The course covers cellular communications technologies as well as the IEEE 802 wireless networking technology family. Key network layer technologies will be discussed, including Mobile IP and Network Mobility (NEMO), layer-2 mesh routing approaches, and layer-3 Mobile Ad-hoc Network (MANET) routing approaches. Security, management, and key performance issues of wireless networks will also be presented.

Prerequisite: 635.411 Foundations of Networking, or equivalent.

Burbank

635.421 Foundations 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.

Felikson, Nag
635.431 **Information Systems Architectures and Methodologies**

This course introduces the fundamental principles which govern information system architecture, data and storage structures, operating systems, data definition and manipulation languages, query structures, and systems analysis as applied to information systems. Hardware considerations for supporting the construction of complex systems are described.

Noble

635.444 **XML: Technology and Applications**

The course covers the concepts, technology, and applications of XML (Extensible Markup Language), especially to Web-based technologies. The course concentrates on XML fundamentals and associated technologies, and processing XML using Java. Topics covered include the XML Specification; XML Namespaces; Document Type Definitions (DTDs); XML Schemas; XML Transformation (XSLT); XML Links and XML Pointers; and parsing XML using the Document Object Model (DOM) and Simple API (Application Programming Interface) for XML (SAX), the Java API for XML Processing (JAXP), and the Java Document Object Model (JDOM). Additional topics may be drawn from Cascading Style Sheets (CSS); XQuery; the Simple Object-Oriented Protocol (SOAP); Web Services Description Language (WSDL); Universal Description, Discovery and Integration (UDDI); applications of XML such as RDF; and the architecture of Web Service, EAI, and B2B systems using XML. (This course is the same as 605.444 XML: Technology and Applications.)

Prerequisite: 605.481 or equivalent Java experience.

Chittargi, Silberberg

635.476 **Information Systems Security**

This course describes the systems security engineering process with a focus on security during the design, implementation, and operation of information systems. The course will present the processes that have been defined and published by the federal government for designing and certifying secure information systems. Examples include defense-in-depth, the Information Assurance Technical Framework and the DITSCAP. There will also be material on commercial and government security products available and the Common Criteria Project for evaluating security products.

Boudra

635.482 **Web Site Development**

This course covers the design and implementation of web sites. 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 web site work well across multiple browsers, and web server selection and configuration.

635.483 **Electronic Commerce**

This course covers the architecture and technologies required to build E-commerce systems. Basic concepts of e-commerce are introduced followed by coverage of the Internet backbone, including fundamental networking infrastructure. The course describes the inadequacy of current World Wide Web technology for e-commerce, which has resulted in the development of the concept of Service-Oriented Architecture (SOA) and its implementation in the form of an Enterprise Service Bus (ESB). SOA and ESB provide a robust and reliable way for service-to-service and business-to-business integration at the data, information and the application levels. Web Services provide the underlying messaging service and is built on four open standards, XML, SOAP, WSDL, and UDDI. The course also introduces the two major frameworks, J2EE and .NET, for building Web services. The critical security and governance issues in SOA implementation along with SOA design and implementation roadmaps are discussed. The second generation Web 2.0 and the AJAX technology are also covered. Finally a software architecture from Business Process Management (BPM) to Grid Computing is presented.

Chi

635.711 **Internetworking: Methods, Technologies, and Devices**

In this course, students learn the methods for interconnecting data networks and creating internetworks. This will cover the LAN internetworking processes and address the extension of LAN coverage and traffic. It will provide the basics for hubs, LAN switching, and router functions. This course will address the methods used in switching and routing as well as some of the gateway requirements used in internetworking. Advanced internetworking topics such as VLANs, MPLS, VPNS, DiffServ and Intserv will be covered. In addition to the study of principles behind internetworking, the course includes a laboratory where students configure networks using switches and routers. Students will also be assigned a network design project.

Prerequisites: A foundations course in data communications (e.g., 635.411) and an advanced course in LANs or IP networking (e.g., 635.412 or 635.413).

Hsu

635.721 **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 web site 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. (This course is the same as 605.766 Human-Computer Interaction.)

Montemayer

635.731 Distributed Architectures
This course explores technologies for enabling distributed systems. Performance, scalability, security, concurrency, synchronization, error handling, and open standards in the context of heterogeneous systems are discussed as a basis for making the distributed nature of systems transparent to users. Key areas covered include client-server systems, coordination and agreement, data encryption, and communications. Students will also investigate advanced topics such as distributed artificial intelligence, mobile agents, storage area networking, distributed databases, and device discovery.

Anderson

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.

Addison and Husick

635.795 Information Systems and Technology 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 IS&T curriculum. The project includes requirements analysis, IT architecture design, network design, software integration, decision support applications, and deployment planning. Interim deliverable 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 IS&T curriculum, including all IS&T foundation courses.

Note: Students may not receive graduate credit for both 635.795 and 635.802 Independent Study in Information Systems and Technology II.

Staff

635.801 Independent Study in Information Systems and Technology I
This course permits graduate students in Information Systems and Technology 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 IS&T 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 member.

635.802 Independent Study in Information Systems and Technology II
Students wishing to take a second independent study in information systems and technology should sign up for this course.

Prerequisites: 635.801 and permission of a faculty mentor, the student’s academic adviser, and the program chair.

Note: Students may not receive graduate credit for both 635.802 and 635.795 Information Systems and Technology 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 engineering develops, modifies, and applies materials to specific technological applications.

The Department of Materials Science and Engineering offers three different graduate degrees; the Ph.D., the M.S.E. (Master of Science in Engineering), and the M.M.S.E. (Master of Materials Science and Engineering). The M.M.S.E. is offered through Engineering and Applied Science Programs for Professionals and is described in detail below. Information about the Ph.D. and M.S.E. can be obtained from the Arts and Sciences/Engineering Undergraduate and Graduate Programs Catalog.

The M.M.S.E. 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 Ph.D. Those interested in pursuing a Ph.D. degree should consider applying to the department for the M.S.E. degree, which requires a formal thesis. Please note that the application materials for the Ph.D. or M.S.E. degrees are different from the Engineering and Applied Science Programs for Professionals application used in applying for the M.M.S.E. degree.

The Department of Materials Science and Engineering has active and well-funded research programs in biomaterials, nanomaterials and nanotechnology, electrochemistry, nondestructive evaluation, thin films, mechanics of 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

Timothy Foecke  
Staff Materials Scientist  
National Institute of Standards & Technology

**Admission Requirements**

The Master of Materials Science and Engineering (M.M.S.E.) 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 either 515.401 Structure and Properties of Materials or 510.601 Structure of Materials; in addition all students must take either 515.402 Thermodynamics and Kinetics of Materials or both 510.602 Thermodynamics of Materials and 510.603 Phase Transformations in Materials. Of the remaining seven 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 adviser.

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.

- 525.406 Electronic Materials
- 525.407 Introduction to Electronic Packaging
- 530.753 Fatigue
- 535.406 Advanced Strength of Materials
- 535.413 Structural Engineering Applications
- 535.720 Analysis and Design of Composite Structures
- 540.426 Introduction to Biomacromolecules
- 540.427 Introduction to Polymer Science
- 540.438 Interfacial Phenomena in Nanotechnology
- 540.439 Polymer Nanocomposites
- 540.627 Microscopic and Macroscopic Analyses of Polymer Solution
- 585.409 Mathematical Methods for Applied Biomedical Engineering
- 585.608 Biomaterials
- 585.609 Cell Mechanics
- 585.618 Biological Fluid and Solid Mechanics
- 615.441 Mathematical Methods for Physics and Engineering
- 615.746 Nanoelectronics: Physics and Devices
- 615.757 Solid State Physics
- 615.760 Physics of Semiconductor Devices
- 615.768 Superlattices and Heterostructure Devices
Nanotechnology Option

Course Requirements
Students enrolled in the Master of Science in Materials Science and Engineering program can elect to pursue the Nanotechnology Option. Two concentrations are offered: the nanomaterials concentration and the biotechnology concentration. For either concentration, the student must successfully complete the core courses and then at least three courses selected from the corresponding concentration 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. A complete description of the requirements is listed in the Nanotechnology Option section.

Required Core Courses
All students are required to take either 515.401 Structure and Properties of Materials or 510.601 Structure of Materials; in addition all students must take either 515.402 Thermodynamics of Materials or both 510.602 Thermodynamics of Materials and 510.603 Phase Transformations in Materials. Additional required core courses for the Nanotechnology option are 515.416 Introduction to Nanotechnology and 515.417 Nanomaterials.

I. Nanomaterials Concentration
Materials Science and Engineering Courses
510.422 Micro- and Nano-Structured Materials and Devices
510.620 Metallic Glasses
510.650 Principles of Quantum Physical Interactions
510.657 Materials Science of Thin Films
515.730-731 Materials Science and Engineering Project

Ⅱ. Biotechnology Concentration
Applied Biomedical Engineering Courses
580.637 Cellular and Tissue Engineering
585.405-406 Physiology for Applied Biomedical Engineering
585.609 Cell Mechanics
585.614 Applications of Physics and Technology to Biomedicine

Chemical and Biomolecular Engineering Course
540.438 Interfacial Phenomena in Nanotechnology

Materials Science and Engineering Course
510.606 Chemical and Biological Properties of Materials
510.617 Advanced Topics in Biomaterials
515.730-731 Materials Science and Engineering Project

Course Descriptions

Courses numbered 600-level and above are open only to students who have been admitted for graduate status.

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.

Note: Also listed as 510.607.

Mao

510.420 Topics in Biomaterials
This course concentrates on molecular structure-property relationships in biomaterials. Special focus will be given to polymers, hydrogels, biodegradable materials, and natural materials. The design of artificial biomaterials for biosensors, drug deliv-
Materials Science and Engineering

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).

Note: Also listed as 510.622

510.426 Biomolecular Materials

Note: Same as 510.626.

510.601 Structure of Materials
This course introduces the structure of inorganic and polymeric materials. Topics include the atomic scale structure of metals, alloys, ceramics, and semiconductors; structure of polymers; crystal defects; elementary crystallography; tensor properties of crystals; and an introduction to the uses of diffraction techniques (including X-ray diffraction and electron microscopy) in studying the structure of materials.

Prerequisite: Undergraduate chemistry, physics, and calculus; or permission of instructor.

510.602 Thermodynamics of Materials
This course introduces the classical and statistical thermodynamics of materials. Topics include the zeroth law of thermodynamics; the first law (work, internal energy, heat, enthalpy, heat capacity); the second law (heat engines, Carnot cycle, Clausius inequality, entropy, absolute temperature); equilibrium of single component systems (free energy, thermodynamic potentials, virtual variations, chemical potential, phase changes); equilibrium of multicomponent systems and chemical thermodynamics; basics of statistical physics (single and multiple particle partition functions, configurational entropy, third law; statistical thermodynamics of solid solutions); and equilibrium composition-temperature phase diagrams.

Prerequisite: Undergraduate calculus, chemistry and physics; or permission of instructor.

510.603 Phase Transformations in Materials
This course presents a unified treatment of the thermodynamics and kinetics of phase transformations from phenomenological and atomistic viewpoints. Phase transformations in condensed metal and nonmetal systems are discussed. Topics include absolute reaction rate theory, thermodynamics of irreversible processes, thermodynamics of surfaces and interfaces, chemical kinetics, nucleation and growth, spinodal decomposition, order-disorder transformations, diffusional transformations, martensitic transformations, coarsening, glass transition.

Prerequisite: 510.601 and 510.602, or permission of instructor.

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 and fracture of polymers.

Prerequisite: 510.601 or permission of instructor.

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 magnetostriiction; 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.

Prerequisite: 510.601.

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.

**Prerequisite:** Undergraduate chemistry and biology, or permission of instructor.

**Yu, Hristova**

**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.

**Prerequisite:** 510.608 or permission of instructor.

**Yu, Hristova**

**510.608 Electrochemistry**

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. Analysis of kinetics at various electrodes, including redox reactions, metal-ion electrodes, and semiconductor electrodes. Electroanalytical techniques are 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.

**Undergraduate prerequisite:** Introductory chemistry or permission of instructor.

**Hufnagel**

**510.609 Electrochemistry Lab**

A series of laboratory experiments is used to illustrate the principles of electrochemistry.

**Prerequisite:** 510.608 or permission of instructor.

**Season**

**510.610 Chemistry and Physics of Semiconductor Surfaces**

Basic principles of bonding, thermodynamics of crystals, surface energy, space charge effects, and potential distributions at phase boundaries are reviewed. Processes related to solid/liquid interfaces including electron transfer, photoeffects, adsorption, catalysis, etching, and oxide formation are covered. Relevant experimental methods, including surface analytical techniques, are reviewed. Examples of applications, including photovoltaic devices and solar cells, are discussed.

**Prerequisite:** 510.608 or permission of instructor.

**Season**

**510.611-612 Solid State Physics**

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 discussed.

**Poehler**

**510.616 Applications of X-Ray Diffraction**

This course introduces the student to crystal structure and what can be learned about materials by a variety of X-ray diffraction, radiographic, topographic and tomographic techniques. The techniques covered include single crystal orientation, single crystal perfection, structure of polycrystalline materials, compositional analysis, and phase identification. An overview will be presented of research efforts illustrating how rapid X-ray diffraction imaging has served to study the plastic deformation of metals, grain boundary migration during recrystallization, and the structure of explosively loaded metals. The utility of X-ray topographic imaging for qualitative assessment of single crystals will be discussed using specific examples of topographic images acquired from nickel-based superalloy turbine blades, gallium-arsenide wafers, and quartz crystal resonators. Finally, the radio-graphic aspect of X-ray imaging will be considered with illustrations given of the application of computer-assisted X-ray tomography. The course will include both classroom lectures and laboratory exercises.

**Hufnagel**

**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, 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.

**510.619 Biopolymers Synthesis**

In this course, we will review the current synthetic methods for preparing biopolymers of both synthetic and natural origin. The class will focus mainly on polypeptides and polysaccharides, but natural polysters and polynucleotides (DNA and RNA) will be covered as well. Some of the main topics are: solid phase peptide synthesis, ring-opening polymerization for polypeptide synthesis, recombinant DNA and bacterial protein synthesis, bacterial production of biodegradable polyester, and chemical and biological engineering of polysaccharides.

**Yu**

**510.620 Metallic Glasses**

Structure, properties, and processing of metallic glasses and amorphous thin films. Particular emphasis on structural characterization of amorphous materials, including X-ray and neutron scattering, EXAFS, small-angle scattering, and anomalous X-ray scattering. Also: phase transformations in amorphous materials, including phase separation and crystalli-
510.622 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).

510.624 Theory of X-ray Diffraction

An introduction to diffraction theory and the uses of diffraction in structural characterization of materials. Topics include X-ray scattering by atoms, kinematic theory, Fourier series methods, diffraction from single crystals and polycrystalline materials, diffraction from multilayers, scattering by liquids and amorphous solids, small-angle scattering, dynamic theory.

510.626 Biomolecular Materials


Note: Also listed as 510.426

510.636 Electronic Materials Science


510.650 Principles of Quantum Physical Interactions

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.

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.

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 multicomponent phase diagrams using CALPHAD modeling.

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 losing sight of the physical meaning. The theories and models obtained will be evaluated critically to determine their validity and limitations. Tentative list of topics to be covered: review of the traditional development of the laws of thermodynamics; alternate formulations (Carathéodory, Truesdell, single axiom approach); equilibrium thermodynamics of Gibb; thermodynamics of solids; thermodynamics of surfaces; principles of statistical thermodynamics; critical phenomena; third law; nonequilibrium thermodynamics (“rational” thermodynamics, thermodynamics of irreversible processes, absolute reaction rates).
515.401  Structure and Properties of Materials
Topics include types of materials, bonding in solids, basic crystallography, crystal structures, tensor properties of materials, diffusion methods, crystal defects, amorphous materials.  Staff

515.402  Thermodynamics and Kinetics of Materials
Topics include laws of thermodynamics, equilibrium of single and multiphase systems, chemical thermodynamics, statistical thermodynamics of solid solutions, equilibrium phase diagrams, chemical kinetics, diffusion in solids; nucleation and growth processes, coarsening, glass transition.  Staff

515.410  Fiber Reinforced Composites
This course acquaints students as well as practicing engineers with the issues needed to deal with composites. Included in the course are a survey of applications and the rationale for usage; an understanding of the mechanics of composites; design characteristics including strength, stability, fatigue, fracture, effects of stress concentrations, and environment; test methods; fabrication, including automation; and quality assurance. Included are several guest lecturers from industry and other universities.

Prerequisite: A basic materials science course or consent of instructor.

515.414  Alloy Selection for Engineering Design
This course examines mechanical property design requirements including code base design requirements. Alloy selection for strength, ductility, fatigue life, cost, fracture toughness, corrosion resistance, and wear are studied. The joining of materials by welding and brazing is addressed. Alloy systems, nomenclature, and physical properties are examined with attention to information sources.

Prerequisites: A basic materials science course or permission of instructor.

515.416  Introduction to Nanotechnology
Nanoscale science and nanotechnology are broad, interdisciplinary areas, encompassing not just materials science but everything from biochemistry to electrical engineering and more. This will be a survey course introducing some of the fundamental principles behind nanotechnology and nanomaterials, as well as applications of nanotechnology. The role of solid state physics and chemistry in nanotech will be emphasized. Nanoscale tools such as surface probe and atomic force microscopy, nanolithography, and special topics such as molecular electronics will also be covered.

Sample

515.417  Nanomaterials
This course will take an in-depth look at nanomaterials discussed in Introduction to Nanotechnology. However, this course stands alone with no prerequisite. Theory and concepts of nanomaterials will be covered, including the chemistry and physics of nanomaterials. The course will also focus on major classes of nanomaterials, including carbon nanotubes, nanostructured materials, nanowires, nanoparticles, nanoclays, and other nanomaterials. Applications of nanomaterials to technology areas of interest to the class will also be discussed.

Sample, Zhang

515.706  Introduction to Composites
This course covers the fundamental aspects of both continuous and discontinuously fiber-reinforced composite materials. Emphasis is placed on continuous fiber organic matrix composites. Material characteristics, fabrication aspects, and micromechanical and macromechanical material characteristics are discussed. Topics include the development and utilization of laminated plate theory for determination of material properties and strengths of composite laminates, flat plate design considerations, and fabrication methods and applications.

Prerequisite: 510.601 or consent of instructor.

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. On completion of this course, a written essay must be submitted. Final approval of the essay will be given by the faculty adviser.

Prerequisites: All other course work should be completed before this project begins (or at least completed concurrently with this project). Consent of adviser is required.

Note: This course is available only to students in the Master of Materials Science and Engineering program.

Two-term course  Staff
Materials and Condensed Matter Option

Materials and condensed matter, technical areas crossing the boundaries of physics and various engineering disciplines, are of growing importance in all our technical activities ranging from sensor development to space science. Although there is a separate degree in Materials Science and Engineering, students can elect to pursue a concentration in materials and condensed matter from the Applied Physics curriculum. This concentration offers students the opportunity to become well grounded in the principles of physics and then apply this knowledge to study leading-edge topics in materials and condensed matter. To do this, students can complete a combination of courses from the Applied Physics, Materials Science and Engineering, Electrical and Computer Engineering, and Chemical and Biomolecular Engineering disciplines. The wide variety of courses from these four areas allows students, working with advisers, to structure a program meeting their professional development needs in materials.

Admission Requirements
Applicants must meet the general requirements for admission to a graduate program outlined in this catalog. In addition, applicants must meet the specific program requirements for Applied Physics (see Graduate Admissions). The special option in Materials and Condensed Matter will be noted on the student’s transcript.

Course Requirements
A total of 10 one-term courses must be completed. Students specializing in Materials and Condensed Matter must complete 615.480 Materials Science, plus three of the six courses listed below:

- 615.441 Mathematical Methods for Physics and Engineering
- 615.442 Electromagnetics
- 615.451 Statistical Mechanics and Thermodynamics
- 615.453 Classical Mechanics
- 615.454 Quantum Mechanics
- 615.465 Modern Physics

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.

Applied Physics offers six additional courses:
- 615.460 Sensors and Sensor Systems for Homeland Security
- 615.746 Nanoelectronics: Physics and Devices
- 615.747 Sensors and Sensor Systems
- 615.757 Solid State Physics
- 615.760 Physics of Semiconductor Devices
- 615.768 Superlattices and Heterostructure Devices

Note: 615.800, Applied Physics Project, and 615.802, Directed Studies in Applied Physics, also can be used to pursue specialized interests in materials and condensed matter.

Electrical and Computer Engineering offers the following courses:
- 525.406 Electronic Materials
- 525.421 Introduction to Electronics and the Solid State I

Materials Science and Engineering offers the following courses:
- 510.420 Topics in Biomaterials
- 510.604 Mechanical Properties of Materials
- 510.606 Chemical and Biological Properties of Materials
- 510.622 Micro- and Nano-Structured Materials and Devices or
- 510.422 Micro- and Nano-Structured Materials and Devices
- 515.417 Nanomaterials

Chemical and Biomolecular Engineering offers the following courses:
- 540.427 Introduction to Polymer Science
- 540.439 Polymer Nanocomposites
Mechanical Engineering

Mechanical engineering is the broadest of the engineering disciplines, and 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 who can lead the profession in a time of rapid change.

The Master of Mechanical Engineering program at Johns Hopkins 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 concentrations: mechanics (either solid mechanics or thermo-fluid mechanics), manufacturing, and robotics and controls. The program has sufficient flexibility to allow students to develop some multidisciplinary strength outside of a concentration. In any case, students are expected to coordinate their selection of courses under the guidance of a faculty adviser.

The degree is awarded on the basis of course work only. No thesis is required. Course offerings are typically structured in two-year cycles.

Program Committee

K. T. Ramesh, Program Chair
Professor of Mechanical Engineering
Whiting School of Engineering

Robert Ivester
Manufacturing Metrology Division
National Institute of Standards and Technology

Jack C. Roberts
Principal Professional Staff
Johns Hopkins Applied Physics Laboratory

Andrea Prosperetti
Charles A. Miller Jr. Distinguished Professor of Mechanical Engineering
Whiting School of Engineering

Louis 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). Each applicant should hold a bachelor’s degree in mechanical engineering or in a closely 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 concentrations: mechanics (either solid or thermo-fluids), manufacturing, and robotics and controls. The following requirements are common to all concentrations. Additional requirements are listed with the course listings for each concentration.

Ten one-term courses, numbered 400-level or above, 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, (this specific course is strongly recommended). The mathematics course must be taken in the first semester of the student’s program, unless the adviser explicitly allows the student to do otherwise. In addition, at least one computationally oriented course is strongly recommended (but not required).

Each concentration has two required courses, and a total of five courses must be chosen from within one concentration. 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 concentrating in one area can take courses offered under one of the other concentrations.

All required courses (within a given concentration) will typically be available at least once a year.

All course selections must be approved by the student’s adviser. A thesis is not required, nor is knowledge of a foreign language.

All courses have as minimum prerequisites the following: undergraduate engineering courses in 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 semester for exact dates, times, locations, fees, and instructors.

I. Mechanics

Within the Mechanics concentration, students may either choose 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 nec-
Mechanical Engineering

essarily all from the same track). The only restriction is that course prerequisites must be fulfilled in all cases.

**Solid Mechanics Track**

- 515.414 Alloy Selection for Engineering Design
- 515.706 Introduction to Composites
- 535.406 Advanced Strength of Materials *(required course)*
- 535.411 Friction and Wear
- 535.412 Intermediate Dynamics
- 535.423 Intermediate Vibrations *(required course)*
- 535.427 Computer-Aided Design
- 535.431 Introduction to Finite Element Methods *(cannot be counted together with 560.730)*
- 535.454 Theory and Applications of Structural Analysis
- 535.476 Nondestructive Evaluation
- 535.620 Orthopedic Biomechanics
- 535.625 Advanced CAD Modeling, Analysis, and Manufacturing
- 535.720 Analysis and Design of Composite Structures
- 560.730 Finite Element Methods *(cannot be counted together with 535.431)*
- 585.609 Cell Mechanics
- 585.618 Biological Fluid and Solid Mechanics

**Thermo-Fluid Mechanics**

- 535.414 Fundamentals of Acoustics
- 535.421 Intermediate Fluid Dynamics *(required course)*
- 535.424 Energy Engineering
- 535.433 Intermediate Heat Transfer *(required course)*
- 535.434 Applied Heat Transfer
- 535.452 Thermal Systems Design and Analysis
- 535.636 Applied Computational Fluid Mechanics
- 585.609 Cell Mechanics
- 585.618 Biological Fluid and Solid Mechanics

**II. Manufacturing Concentration**

- 515.414 Alloy Selection for Engineering Design
- 515.706 Introduction to Composites
- 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)*
- 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)*
- 535.472 Advanced Manufacturing Systems
- 535.474 Quality Assurance Engineering
- 535.476 Nondestructive Evaluation
- 535.625 Advanced CAD Modeling, Analysis, and Manufacturing
- 595.460 Introduction to Project Management
- 595.760 Quality Management

**III. Robotics and Controls Concentration**

- 525.409 Continuous Control Systems
- 525.763 Applied Nonlinear Systems
- 535.412 Intermediate Dynamics
- 535.423 Intermediate Vibrations
- 535.426 Kinematics and Dynamics of Robots *(required course)*
- 535.427 Computer-Aided Design
- 535.428 Computer-Integrated Design and Manufacturing
- 535.435 Integrated Computer Vision and Robot Motion Planning
- 535.442 Control Systems for Mechanical Engineering Applications *(required course)*
- 535.454 Theory and Applications of Structural Analysis
- 535.459 Manufacturing Systems Analysis
- 535.625 Advanced CAD Modeling, Analysis, and Manufacturing
- 535.726 Robot Control
Course Descriptions

The courses listed with the prefix 535 are offered one night per week. Courses with the prefix 530 are usually offered during the day as part of the full-time graduate program in mechanical engineering.

530.487 Introduction to Microelectromechanical Systems (MEMS)
For engineering and science majors. An introduction to materials and basic devices with examples of applications for sensing and actuation. Lectures will be complemented with a set of laboratory experiments.
Prerequisite: Senior or graduate standing or permission of instructor.
Sharpe

530.495 Microfabrication Laboratory
This laboratory course is an introduction to the principles of microfabrication for microelectronics, sensors, MEMS, and other synthetic microsystems that have applications in medicine and biology. Course comprised of laboratory work and accompanying lectures that cover silicon oxidation, aluminum evaporation, photore sist deposition, photolithography, plating, etching, packaging, design and analysis CAD tools, and foundry services.
Wang

530.496 Micro/Nanoscience and Biotechnology
An introduction to the physical and chemical principles important to MEMS, BioMEMS, and bionanotechnology. Topics include scaling laws, colloids and surfaces, micro and nanofluidics, thermal forces and diffusion, chemical forces, electrokinetics, electric aspects of surface chemistry, capillary forces and surface tension, and top-down and bottom-up nanofabrication.
Wang

530.652 Bridging Length Scales in Materials Behavior
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.
Hemker

530.753 Fatigue
High-cycle and low-cycle fatigue. Constant amplitude and spectrum loading. Phenomenological relations. Special emphasis on notches and on short cracks. Offered only occasionally.

535.406 Advanced Strength of Materials
This is a practical course in advanced strength of materials that uses design techniques to solve complex problems. It focuses on newly developed experimental techniques that allow simplification of previously unsolvable problems to something that can be quickly “estimated.” It concentrates on stresses in torsion, shear and bending, stress concentration effects, stability, fatigue, fracture mechanics, general design criteria, cantilever beams with different boundary conditions, variable section cantilever beams, beams with different constraints, curved bars and hooks, plates and flanges, panels and closures, flanges and brackets, weld analysis, pressure vessels (thick and thin), and combined axial and bending response of beams and cylinders.
Roberts

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 pre-cursor 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).
Spring

535.411 Friction and Wear
This course provides basic concepts for understanding contact, friction, and wear. An introduction to different forms of friction and wear and to the necessary elements of continuum mechanics is followed by an examination of pressure and stress distributions and the interaction of rough surfaces. Frictional effects, including fretting, microslip, and rolling-sliding contact, are also discussed. Students examine the mechanics of lubrication, including hydrodynamic and elastohydrodynamic lubrication, film thickness effects, and the friction inside a lubricant layer. The course concludes with industrial applications, including the design of ball and roller bearings, the selection of lubricants for bearings and gears, and the design of antifriction and wear-resistant coatings. Offered only occasionally.
Prerequisite: An undergraduate course in strength of materials.

535.412 Intermediate Dynamics
This course covers kinematics and dynamics of systems of particles and rigid bodies undergoing planar and general 3-D motion. Applications of the conservation equations are reviewed in the context of mass-flow and impact. Vectorial 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.
535.413  Structural Engineering Applications
This course covers case histories of structural applications from large scale truss structures, avionics, space, electronics, biomedical, composite ship hulls, torpedoes, etc. The emphasis is placed not only on the types of solutions, i.e., hand structural analysis, finite element analysis, and statistics, but also on the problems encountered in obtaining requirements, interpreting those requirements, applying the requirements, and reporting the results.

535.414  Fundamentals of Acoustics
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.

Prerequisite: Some familiarity with linear algebra, complex variables and differential equations.

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, 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. The course includes a programming project to develop a numerical solution to a practical fluid flow problem.

Prerequisite: An undergraduate fluid mechanics course.

Hess

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. Offered only occasionally.

Conn

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.

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 2nd law of thermodynamics. It is applicable to all types of thermodynamic systems but since the text focuses on traditional power and refrigeration systems, so will the course. However, non-traditional 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. Lectures will follow the textbook, and the student will be responsible for a selected number of text problems, upon which the test(s) will be literally based. Offered only occasionally.

Lamb

535.425  Computer Vision
This course gives an overview of fundamental methods in computer vision from a computational perspective. Methods include computation of 3-D geometric constraints from binocular stereo, motion, texture, shape-from-shading, and photometric stereo. Edge detection and color perception are studied as well. Elements of machine vision and biological vision are also discussed. Offered only occasionally.

Waters

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.

Lovell

535.427  Computer-Aided Design
This course explores many aspects of the design and development process, introducing Computer-Aided Design (CAD) as the unifying element of the process. Solid and assembly modeling, as well as structural and kinematic analysis techniques using IDEAS software (Structural Dynamics Research Corporation) are used within the framework of the design process to complete assigned projects. (IDEAS will be run on the workstations on the Homewood campus.) Topics covered include design theory, design for manufacturing and assembly (DFMA), geometric dimensioning and tolerance (GD&T), quality, and electromechanical packaging.

Prerequisites: An undergraduate machine design course and some familiarity with the UNIX operating system.

Rothman
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 manufacturing (CAM), robotics, material resource planning, tool management, information management, process control, quality control, etc. The current capabilities, applications, limitations, trends, and economic considerations are stressed.

Ivester

Prerequisite: Systems.

535.429 Robotic 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: Kinematics and Dynamics of Robots, Ordinary Differential Equations, Linear Algebra.

Patriciu

535.431 Introduction to Finite Element Methods

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 upon developing a fundamental understanding of the method and its application.

Lear

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.

Oguz

535.434 Applied Heat Transfer

This course focuses on the inevitable trade-offs 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 co-generation systems.

Prerequisite: An undergraduate heat transfer course.

Didion

535.435 Integrated Computer Vision and Robot Motion Planning

This course will cover topics in computer vision including computation of 3-D geometric constraints from binocular stereo and edge detection. Topics in motion planning include motion of rigid objects by the configuration space approach, motion of linked robot arms, motion in an unknown environment, and tracking. Students will design and build a robot motion planner with visual feedback and tracking. Offered only occasionally.

Prerequisites: Linear algebra and linear differential equations.

Conn, Waters

535.441 Mathematical Methods for Engineers

This course covers a broad spectrum of mathematical techniques needed to solve advanced problems in engineering. Topics include ordinary differential equations, complex variables, integral transforms, vectors and matrices, special functions, and partial differential equations. 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.

Nakos

535.442 Control Systems for Mechanical Engineering Applications

This course presents an overview of the current control elements and processes for mechanical and electromechanical systems used in standard engineering practice. Various systems, including thermal and fluid models, are described with particular emphasis placed on computer control applications. Analysis is performed on commonly used servomechanisms and design and stability criteria are investigated.

Konopacki

535.443 Computational Heat Transfer

This course presents various methods used in modeling and simulating heat transfer processes associated with complex, realistic physical systems. Coupled conduction, convection, and radiation effects are analyzed. Finite difference concepts are also examined along with the stability and convergence criteria of the models. Several of the commercial large scale heat transfer codes are introduced. Matlab is used for course assignments. Offered only occasionally.

Prerequisite: An undergraduate course in heat transfer.

Konopacki

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; multiphase 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. Offered only occasionally.


535.452 Thermal Systems Design and Analysis
Thermodynamics and heat transfer principles are applied to power and refrigeration systems with emphasis on economic and performance trade-offs. Where it has practical value, the use of second law analysis (i.e., an entropy inventory) is introduced. The mathematical modeling of thermal elements and complex systems is developed to minimize primary energy consumption while meeting variable load patterns. This leads to the use of an advanced PC-based equation solver software package for simulation and numerical solution. The necessary software is provided to the students.

Prerequisites: Undergraduate courses in thermodynamics and heat transfer. No computer programming is required.

Didion

535.453 Fundamentals of Applied Thermal Systems
This course deals with the engineering science behind the vapor compression and absorption cycles, psychrometrics, and heat exchange through the use of extended surfaces and direct contact between liquid and vapor. The processes that go on in positive displacement and centrifugal compressors, condensers, evaporators, expansion devices, absorbers and rectifiers, cooling towers, air washers and spray dehumidifiers will be studied. While the course emphasis is primarily on traditional thermal science processes, at least one lecture will be on their environmental impact since the energy resources, ozone and climate change problems have become new criteria for thermal machine design. Offered only occasionally.

Prerequisites: 535.433 Intermediate Heat Transfer or permission of instructor.

Didion

535.454 Theory and Applications of Structural Analysis
Course topics include classical shell structures; twisting and bending of single cell open section structures; twisting and bending of closed section structures; pure twisting of multi-celled structures; bending of multi-celled structures; classical plate theory; applications of bending and buckling of plates in multi-celled structures; and finite element analysis of structures.

Roberts

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 which affect the cost, quality, cycle time, and maintainability.

Staff

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.

Staff

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.

Staff

535.474 Quality Assurance Engineering
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, Demings P-D-S-A 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 9000 standards are discussed. Offered only occasionally.

Ali

535.476 Nondestructive Evaluation
An introduction to the nondestructive evaluation of engineering materials and systems for the purpose of determining their
structural integrity or physical characteristics. Ultrasonic, radiographic, eddy current, magnetic and acoustic emission techniques, among others, are considered for presentation. Course material will emphasize quantitative methods and techniques. Both instructor demonstrations and hands-on student activities will be used to reinforce course material.

535.481 Commercial Nuclear Reactors
This is an introductory course to commercial nuclear power plant operation from a heat transfer and thermal-hydraulics perspective. You will gain a working knowledge of criticality theory and reactivity management, the two basic domestic light water reactor designs (Pressurized Water Reactors and Boiling Water Reactors), and the practical problems resulting from large scale one and two phase flow heat transfer. While the course will involve some problem solving, the main thrust is to provide a conceptual understanding of the design and theory of operation of light water reactor fluid systems.

Merschoff

535.620 Orthopedic Biomechanics
This course is an introduction to the field of orthopedic biomechanics for the engineer. The course will cover the structure and function of the musculoskeletal system, including detailed discussions on the material properties of bone, ligament, tendon, cartilage, and muscle. Other topics of discussion will include viscoelasticity, bone remodeling, and injury mechanisms. Journal articles from the biomechanics literature will be used to explore current areas of active research.

Offered only occasionally.
Prerequisites: Statics required and dynamics recommended.
Kleinberger

535.625 Advanced CAD Modeling, Analysis, and Manufacturing
The course presents advanced mechanical design techniques using the Pro/ENGINEER (PTC, Inc.) CAD/CAM software. The course gives 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 sections includes practical examples with 3-5 axes Vertical Machining Centers (HAAS FV-1&2) and a Turning CNC center (HAAS SL-20).

Offered only occasionally.
Prerequisites: Knowledge and experience with basic ProE parts and assembly management.
Stoianovici

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. Offered only occasionally.
Prerequisites: 535.421 Intermediate Fluid Dynamics and 535.441 Mathematical Methods for Engineers. Students should have a least one basic course in fluid dynamics, one course in ordinary differential equations and some familiarity with partial differentia.
Janajreh

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.
Roberts

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. Offered only occasionally.
Prerequisites: 535.426 Kinematics and Dynamics of Robots, Ordinary Differential Equations, Linear Algebra.
Patriciu
Nanotechnology Option

Nanotechnology involves science and engineering on the nanometer scale, generally less than or of order 100nm. It involves the design, synthesis, and processing of nanoscale structures for engineering applications. In some cases this can involve the assembly of materials one molecule or even one atom at a time. At these small length scales, materials often display novel behavior that can be exploited technologically. For example, in the area of nanoelectronics, there has been an intense effort toward continued miniaturization of semiconductor devices in order to increase the density of transistors in integrated circuits or to exploit quantum mechanical effects that occur only when the length scale is reduced to the nanoscale range. Nanomaterials also display enhanced mechanical, optical, magnetic, and chemical properties that offer a wide variety of technological uses. Recently nanotechnology has also become extremely important in the area of biotechnology, allowing for the study of the science and engineering of biological materials for a variety of medical applications.

Admission Requirements
Applicants must meet the requirements for admission into the Master of Materials Science and Engineering (M.M.S.E.) program. The program is best suited for 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 also meet the general requirements for study outlined in this catalog. The program committee is willing to consider applicants who do not meet the general admission requirements only in exceptional cases.

Course Requirements
Students enrolled in the Master of Science in Materials Science and Engineering program can elect to pursue the Nanotechnology Option. Two concentrations are offered: the nanomaterials concentration and the biotechnology concentration. For either concentration, the student must successfully complete the core courses and then at least three courses selected from the corresponding concentration 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.

Required Core Courses
- 510.601 Structure of Materials or 515.401 Structure and Properties of Materials
- 510.602 Thermodynamics of Materials and 510.603 Phase Transformations in Materials or 515.402 Thermodynamics and Kinetics of Materials
- 515.416 Introduction to Nanotechnology
- 515.417 Nanomaterials

Nanomaterials Concentration
Materials Science and Engineering Courses
- 510.422 Micro-and Nano-Structured Materials and Devices
- 510.620 Metallic Glasses
- 510.650 Principles of Quantum Physical Interactions
- 510.657 Materials Science of Thin Films
- 515.730-731 Materials Science and Engineering Project

Applied Physics Courses
- 615.746 Nanoelectronics: Physics and Devices
- 615.747 Sensors and Sensor Systems
- 615.768 Superlattices and Heterostructure Devices

Mechanical Engineering Courses
- 530.487 Introduction to Microelectromechanical Systems (MEMS)
- 530.652 Bridging Length Scales in Materials Behavior

Chemical and Biomolecular Engineering Courses
- 540.438 Interfacial Phenomena in Nanotechnology
- 540.439 Polymer Nanocomposites

Geography and Environmental Engineering Course
- 570.429 Surface Effects of Technological Processes and Materials

Any course from the Biotechnology Concentration list (see below).

Biotechnology Concentration
Materials Science and Engineering Courses
- 510.606 Chemical and Biological Properties of Materials
- 515.730-731 Materials Science and Engineering Project

Chemical and Biomolecular Engineering Course
- 540.438 Interfacial Phenomena in Nanotechnology
Applied Biomedical Engineering Courses

580.637 Cellular and Tissue Engineering
585.405-406 Physiology for Applied Biomedical Engineering
585.608 Biomaterials
585.609 Cell Mechanics
585.614 Applications of Physics and Technology to Biomedicine

Course Descriptions

Please refer to the section in the catalog concerning each degree program for the description of the courses given by that program. Some courses are not offered every year. Dates, times, locations, fees, and instructors are given in the course schedule published each term.
Photonics Option

Photonics, a technical area crossing the boundaries of physics and electrical engineering, continues to be of considerable importance in our technical activities. Although there is no separate degree curriculum in photonics, students can elect to pursue a concentration in photonics from either the Applied Physics or Electrical and Computer Engineering curricula. To do this, students can complete a combination of courses selected from both the Applied Physics and Electrical and Computer Engineering disciplines. The wide variety of courses from both areas allows students, working with advisers, to structure a program meeting their professional development needs.

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

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

Applied Physics students specializing in photonics must complete three required courses:
- 615.441 Mathematical Methods for Physics and Engineering
- 615.442 Electromagnetics
- 615.454 Quantum Mechanics

The seven additional courses must include five or more from the lists below.

Electrical and Computer Engineering students specializing in photonics must complete the following three required 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: 615.800 Applied Physics Project and 615.802 Directed Studies can also be used to allow the student to pursue specialized interests in photonics.

Electrical and Computer Engineering courses:
Electrical and Computer Engineering students specializing in photonics must complete three required 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.

Course Descriptions
Courses numbered 600-level and above are open only to 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.
Systems Engineering

Systems engineering is that part of the technical management process that 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. Systems engineering currently enjoys growing importance and recognition as a distinct discipline, widely sought by both industry and government.

The Master of Science in Systems Engineering program is designed to address the specific needs of engineers and scientists engaged in all aspects of analysis, design, integration, production, and operation of modern systems. Since systems engineering is essentially an experience-based rather than a knowledge-based subject, the program makes use of practicing professional systems engineers as instructors. The methodology employs a combination of lectures and readings on theory and practice, together with realistic problem situations in which students, either individually or as members of small teams, learn to apply the principles, tools, and skills they learn. The educational objective is to provide students with both theoretical and practical knowledge, skills, and tools; a systematic approach to problem solving; and the confidence to solve complex system problems.

Students are encouraged to pursue the entire master’s degree, but in special approved cases may apply for a Graduate Certificate in Systems Engineering. 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 A or B (see Admission Requirements).

Program Committee

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Jerry A. Krill
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Nicholas J. Langhauser
Principal Professional Staff
Applied Physics Laboratory

Ronald R. Luman
Principal Professional Staff
Applied Physics Laboratory

Admission Requirements

Applicants must meet the general requirements for admission to a graduate program outlined in this catalog (see Admission Requirements under General Information). In addition, the applicant should have a degree in a technical field and have a minimum of two years of appropriate full-time work experience in that field. A resume must be submitted with the application form.

Course Requirements

Prior or concurrent completion of 645.467 Management of Systems Projects and 645.462 Introduction to Systems Engineering (taken in either order) is generally a prerequisite to more advanced courses in the systems engineering curriculum. Specific prerequisites for each course are shown under the individual course descriptions. An approved program plan is required for preferential placement in registering.

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.

All students must satisfactorily complete 10 one-term courses. The core curriculum of eight required courses includes:

- 595.763 Software Engineering Management
- 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
- 645.770 Systems Engineering Project

In addition, select one from the following:

- 645.742 Management of Complex Systems
- 645.753 Enterprise Systems Engineering
- 645.761 Systems Architecting
- 645.771 Systems of Systems Engineering

This student-selected course can only be taken after completion of 645.770. The course descriptions for these four courses can be found in the Systems Engineering Advanced Certificate for Post-Master’s Study catalog section.
Electives

Two relevant electives may be selected from the technical management, applied biomedical engineering, applied physics, computer science, electrical engineering, environmental engineering and science, and information systems and technology programs. Individual courses (595 series) are described in the current catalog under the technical management program section.

Course Descriptions

Systems Engineering courses are primarily for those students who have been accepted as candidates for the master’s degree. Courses numbered 600-level and above are open only to students who have been admitted to graduate status.

Courses are offered at the APL Education Center, the Montgomery County Campus, the Dorsey Center, and the Southern Maryland Higher Education Center. Please refer to the Course Schedule published each term for exact dates, times, locations, fees, and instructors.

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.

Prerequisite: Admission into the Systems Engineering program.

Biener, Britcher, Flanagan, Russell, Ryder, Smith, Smyth, Utara, Wilmot

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 and who must address typical problems that arise in the conduct of a high-technology systems project.

Prerequisite: Admission into the Systems Engineering program (not available for Technical Management students).

Biener, Britcher, Flanagan, Russell, Ryder, Smith, Smyth, Utara, Wilmot

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 which 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 trade-offs, 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: 595.460 Introduction to Project Management and 645.462 Introduction to Systems Engineering, or permission of the student’s adviser and the course instructor.

Biener, Britcher, Flanagan, Russell, Ryder, Smith, Smyth, Utara, Wilmot

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 plan, 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.  
Prerequisite: 645.767 System Conceptual Design or permission of the student's adviser and the instructor.

Britcher, Happel, Holab, McLoughlin, Schulmeyer, Utara

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.  
Prerequisite: 645.768 System Design and Integration or permission of the student's adviser and the instructor.

Kryzstan, Pardoe, Schulmeyer, Sprigg, Tuck, Wynne

645.770 Systems Engineering Project

This course provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific practical project, which 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 oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the system 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. 
Prerequisite: 645.769 System Test and Evaluation or permission of the program chair or vice chair.

Seymour
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, comprehensive approach is needed to develop sophisticated architectures, employ innovative enterprise management processes, and deploy global high technology products, often comprised of multiple systems. This graduate program is designed to provide senior engineers and managers, who already have a master’s degree in systems engineering, advanced state-of-the-art tools and knowledge that goes beyond the traditional systems engineering program.

The objective of the Johns Hopkins University 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 improving the systems engineering practices in complex technology-based programs. Current definitions, methodologies, tools, and technologies used in academia, government, and industry will be explored.

The program builds upon the existing JHU EPP MS Program in Systems Engineering that provides an integrated foundation course series based on the acquisition project life cycle. The hundreds of JHU MS SE graduates over the last 15 years and the SE graduates of other institutions are now engaged in leading their organizations in programs of increasing value and complexity.

This certificate program will provide the opportunity to expand the student’s experience and knowledge horizons to encompass the enterprise and integrated systems environments. An emphasis on commercial and government challenges will be explored. The courses are taught by current advanced systems engineering practitioners who are intimately familiar with the current challenges facing government and industry. Students should continue to expect relevant, applied, meaningful hands-on learning experiences coupled with sound research into the latest problems facing systems engineering.

Admissions Requirements

Applicants must have completed a Master of Science degree in Systems Engineering; or a Master of Science in a technical field such as EE, ME, CS, etc., plus a minimum of 10 years of professional experience as a practicing systems engineer; or a Master of Science in a technical field such as EE, ME, CS, etc., plus a minimum of five years of professional work experience as a practicing systems engineer, plus the completion of the Introduction to Systems Engineering course, 645.462. Eligibility will be determined by a current resume and verification in an employer recommendation letter. Graduates of The Johns Hopkins University must supply evidence of their Systems Engineering degree through a copy of their transcript. Systems Engineering M.S graduates of other institutions must request official transcripts be sent to JHU.

Course Requirements

The Systems Engineering Advanced Certificate for Post-Master’s Study is awarded after completion of six courses beyond the Master of Science 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 adviser. The two electives can both be an independent systems engineering research project leading to a paper suitable for submission for publication in a refereed journal.

Required Courses

- 645.742 Management of Complex Systems
- 645.753 Enterprise Systems Engineering
- 645.761 Systems Architecting
- 645.771 Systems of Systems Engineering

Elective Courses

- 645.775 Advanced Systems Engineering Research Project (2 semesters)
  or
- Two approved 700-level courses in the EPP offering

Course Descriptions

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.

Prior to: MS in Systems Engineering.

645.753  Enterprise Systems Engineering

Enterprise Systems Engineering is a multidisciplinary approach combining system 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 system 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 ROI 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.

Prior to: MS in Systems Engineering.

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 as a subset of broad systems engineering when developing individual systems and systems which are components of a systems of systems 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, extending 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 communication 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.

Prior to: MS in Systems Engineering.

645.771  Systems 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, confederated 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 system of systems, including missile defense and combatant vehicle design, as well as selected commercial examples.

Prior to: MS in Systems Engineering.

645.775  Advanced Systems Engineering Research Project

This course is designed for students in the Systems Engineering Post-Master’s Advanced Certificate Program, working with an adviser 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.

Prior to: MS in Systems Engineering and three of the four required Advanced Post-Master’s Systems Engineering courses.
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, nothing in their past education and little in their work experience has prepared them for supervisory and management responsibilities.

The overall objective of this program is to prepare individuals trained and experienced in science or engineering in the elements of managing technical projects and organizing and supervising technical personnel. The program is organized along four parallel tracks: Project Management—the organization and direction of specific technical projects; Organization Management—the organization and supervision of people to accomplish technical objectives; and Project/Organization Management—a combination of the previous two tracks. A concentration in Technical Innovation Management addresses the personal and organizational management of innovation and the development of new technical ventures.

Instructional methodology employs a mixture of lectures on theory and practice by experienced technical managers 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 a 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 A or B (see Admission Requirements).

Program Committee

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Principal Professional Staff
Applied Physics Laboratory

Nicholas J. Langhauser
Principal Professional Staff
Applied Physics Laboratory

Ronald R. Luman
Principal Professional Staff
Applied Physics Laboratory

Admission Requirements

Applicants must meet the general requirements for admission to a graduate program outlined in this catalog (see Admission Requirements). In addition, the applicant must have a degree in a science or engineering field and must have a minimum of five years of appropriate full-time work experience in that field. A resume must be submitted with the application form.

Course Requirements

All students complete 10 one-term courses within five years. Students may elect to pursue a concentration in Project Management, Organization Management, Project/Organization Management, or Technical Innovation 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.

I. Required Courses for Project Management
(7 courses)

595.460 Introduction to Project Management
595.461 Technical Group Management
595.464 Project Planning and Control
595.465 Communications in Technical Organizations
595.466 Financial and Contract Management
595.763 Software Engineering Management
645.462 Introduction to Systems Engineering

II. Required Courses for Organization Management
(7 courses)

595.460 Introduction to Project Management
595.461 Technical Group Management
595.463 Technical Personnel Management
595.464 Project Planning and Control
595.465 Communications in Technical Organizations
595.466 Financial and Contract Management
595.762 Management of Technical Organizations
III. Required Courses for Project/Organization Management (9 courses)

- 595.460 Introduction to Project Management
- 595.461 Technical Group Management
- 595.463 Technical Personnel Management
- 595.464 Project Planning and Control
- 595.465 Communications in Technical Organizations
- 595.466 Financial and Contract Management
- 595.762 Management of Technical Organizations
- 595.763 Software Engineering Management
- 645.462 Introduction to Systems Engineering

IV. Required Courses for Technical Innovation Management (10 courses)

- 595.460 Introduction to Project Management
- 595.461 Technical Group Management
- 595.464 Project Planning and Control
- 595.465 Communications in Technical Organizations
- 595.466 Financial and Contract Management
- 595.468 Fundamentals of Technical Innovation in Organizations
- 605.791 New Technical Ventures
- 635.792 Management of Innovation

And two courses from:

- 595.463 Technical Personnel Management
- 595.762 Management of Technical Organizations
- 595.763 Software Engineering Management
- 645.462 Introduction to Systems Engineering

V. Elective Courses for Project Management, Organization Management, and Project/Organization Management Concentrations

- 595.468 Fundamentals of Technical Innovation in Organizations
- 595.760 Quality Management
- 595.766 Advanced Technology
- 605.791 New Technical Ventures
- 635.792 Management of Innovation

Permission may also be granted by the chair/vice chair to take certain relevant courses in other EPP programs as electives.

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, providing 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-level and above are open only to students who have been admitted to graduate status.

Courses are offered at the 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.

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, 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 five years’ work experience in science or engineering.

Bates, Buchanan, Dabbah, Finlayson, Krueger, Powers, Supplee, Tuck, Wheeler

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 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
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.
Prerequisite: 595.461 Technical Group Management or permission of the student’s adviser or the course instructor.
Buckman, Dickson, Jackson, Lasky

595.464 Project Planning and Control
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; value earned performance measurement; analysis of project performance measures; integrated project planning; new product development considerations; and enterprise information systems applications.
Prerequisites: 595.460 Introduction to Project Management or the permission of the student’s adviser or the course instructor.
Chism, McLoughlin, Utara, Wheeler

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.
Prerequisite: 595.460 Introduction to Project Management or 595.461 Technical Group Management, completed or taken concurrently.
Moazami, Thompson, Williamson

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, highlighting the distinctive characteristics of contracting with the federal government is presented, as well as emphasis on a 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.
Prerequisite: 595.460 Introduction to Project Management or 595.461 Technical Group Management, completed or taken concurrently.
Langhauser, Warner, Williamson, Wyant

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. This course will draw on interdisciplinary concepts from the technical and managerial fields of studies. The course 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, product-process lifecycle vis-a-vis international trade patterns.
Sharif

595.760 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/
teamwork, 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. This course requires a final applied research paper.

Prerequisite: 595.460 Introduction to Project Management, 595.461 Technical Group Management, or permission of the student's adviser and the instructor.

595.762 Management of Technical Organizations
This course reviews problems 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; organizing, 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: 595.463 Technical Personnel Management, 595.464 Project Planning and Control, or permission of the student's adviser and the instructor.

Fountain, Potocki, Suter

595.763 Software Engineering Management
This course covers software engineering principles and software tools and techniques as applied to the development of software systems. Topics include differences between software engineering and conventional programming; understanding the important issues in managing software engineering; understanding the basic concepts of software development using software engineering principles; software-unique aspects of project management; software development facilities and discussing some of the technologies and management trends in software engineering today. Students may examine case studies from their own environment as well as develop a plan for a notional project.

Prerequisite: 645.462 Introduction to Systems Engineering or permission of the student's adviser or the course instructor. Completion of 595.460 Introduction to Project Management is helpful.

Britcher, Houle-Caruso, Miklos, Mosley, Reid, Saunders, Zitzman

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.

Prerequisite: 595.460 Introduction to Project Management and/or 645.462 Introduction to Systems Engineering or permission of the student's adviser and the instructor.

Seymour, Strawser, Suter
Telecommunications and Networking Option

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 Engineering and Applied Science Programs for Professionals do not offer a separate master’s degree in telecommunications and networking, students may pursue an option in this area as degree candidates in either computer science or electrical and computer engineering. The wide variety of courses from both areas allows students, working with advisers, to structure programs that meet their professional development needs.

Admission Requirements

Applicants must meet the general requirements for admission to graduate programs outlined in this catalog in the general Admission Requirements section. In addition, applicants must meet the specific program requirements for either computer science or electrical and computer engineering (see those programs for specific admission information).

Course Requirements

Each degree candidate is assigned an adviser. Attainment of the degree requires completion of 10 one-term courses specifically approved by the adviser. Seven of the 10 courses must be in the telecommunications and networking subject area as defined by the course lists below. 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. The requirements for computer science degree candidates and those for electrical and computer engineering candidates can be found in the program descriptions in the respective sections of the catalog. Students who select the telecommunications and networking option through the computer science program may take a maximum of three telecommunications and networking courses from electrical and computer engineering courses listed below. Electrical and computer engineering students who select the telecommunications and networking option are required to take either two or three computer science telecommunications and networking courses as electives. All of these electives must be selected from the computer science courses listed below.

Computer Science

605.434 WWW Security
605.471 Principles of Data Communications Networks
605.472 Computer Network Architectures and Protocols
605.475 Protocol Design
605.477 Internetworking with TCP/IP I
605.478 Cellular Communications Systems
605.731 Network Security
605.732 Cryptology
605.771 Wired and Wireless Local and Metropolitan Area Networks
605.772 Network Management
605.773 High-Speed Networking Technologies
605.774 Network Programming
605.775 Optical Networking Technology
605.777 Internetworking with TCP/IP II
605.778 Voice over IP

Electrical and Computer Engineering

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
525.437 Telecommunications Signal Processing
525.438 Introduction to Wireless Technology
525.439 Introduction to High-Speed Networks
525.440 Satellite Communications Systems
525.441 Computer and Data Communication Networks I
525.444 Introduction to ATM Networks and Video Applications
525.707 Error Control Coding
525.722 Wireless and Mobile Cellular Communications
525.723 Computer and Data Communication Networks II
525.738 Advanced Antenna Systems
525.747 Speech Processing
525.751 Software Radio
525.754 Wireless Communication Circuits I
525.755 Wireless Communication Circuits II
525.759 Image Compression, Packet Video, and Video Processing
525.761 Wireless and Wireline Network Integration
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
525.795 Advanced Communications Laboratory

Course Descriptions

See the computer science or electrical and computer engineering sections for course descriptions.
Policy Statements

Equal Opportunity/Nondiscriminatory Policy
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 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, 130 Garland Hall, Telephone: 410-516-8075, TTY: 410-516-6225.

Policy on the Reserve Officer Training Corps (ROTC)
Present Department of Defense policy governing participation in university-based ROTC programs discriminates on the basis of sexual orientation. Such discrimination is inconsistent with the Johns Hopkins University nondiscrimination policy. Because ROTC is a valuable component of the university that provides an opportunity for many students to afford a Hopkins education, to train for a career, and to become positive forces in the military, the university, after careful study, has decided to continue the ROTC program and to encourage a change in federal policy that brings it into conformity with the university’s policy.

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 Part-Time Programs in Engineering and Applied Science complies with the provisions of the Family Educational Rights to Privacy Act of 1974 (P.L. 93-380), as amended, and regulations promulgated thereunder. The Family Educational Rights and Privacy Act (FERPA) affords eligible students, with certain rights with respect to their education records. They are (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 the amendment of the student’s education records that the student believes are inaccurate or misleading. Students should write 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. Government 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 faculty, staff and students 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 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 Disability Support Services Web site at www.jhu.edu/disabilityservices. 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 Peggy Hayeslip, director, ADA Compliance and Disability Services, Office of Institutional Equity, 130 Garland Hall, 410-516-8949 or (TTY) 410-516-6225.

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 only exist 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 students, Levering Hall, telephone 410-516-8208; Ray Gillian, vice provost for institutional equity; or Caroline Laguerre-Brown, director, equity compliance and education, 130 Garland Hall, telephone 410-516-8075, TTY 410-516-6225.

University Alcohol and Drug Policy for Students
In keeping with its basic mission, the Johns Hopkins 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 university, and copies are available on request from the offices of the Faculty and Staff Assistance Program, 4 East 33rd Street, Baltimore, Maryland 21218; telephone 410-516-3800; or at the Counseling and Student Development Center located on the Homewood campus; telephone 410-516-8270.

Policy on Possession of Firearms on University Premises
The possession, wearing, carrying, transporting, or use of a firearm or pellet weapon is strictly forbidden on Johns Hopkins 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 (PL 102-26), as amended, and the regulations promulgated thereunder, the Johns Hopkins 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 www.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; telephone 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 Web site, 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—which will be kept in the files and archive of The Johns Hopkins University, will 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% 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% 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:

\[
\text{Percentage of payment period or term completed} = \frac{\text{number of days completed up to the withdrawal date}}{\text{total days in the payment period or term}}.
\]

Any break of five days or more is not counted as part of the days in the term. This percentage is also the percentage of earned aid.

Funds are returned to the appropriate federal program based on the percentage of unearned aid using the following formula:

\[
\text{Amount to be returned} = (100\% \text{ of the aid that could be disbursed minus the percentage of earned aid}) \times \text{the total amount of aid that could have been disbursed during the payment period or term}.
\]

If a student earned less aid than was disbursed, the institution would be required to return a portion of the funds and the student would be required to return a portion of the funds. Keep in mind that when Title IV funds are returned, the student borrower may owe a debit balance to the institution.

If a student earned more aid than was disbursed to him/her, the institution would owe the student a post-withdrawal disbursement which must be paid within 120 days of the student’s withdrawal.

The institution must return the amount of Title IV funds for which it is responsible no later than 30 days after the date of the determination of the date of the student’s withdrawal.

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)
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NSA

Gerald H. Zueldsorf  
Senior Electrical Engineer  
NSA
Directions and Maps

Applied Physics Laboratory
Education Center
From Baltimore and I-95 (southbound): Take I-95 South from the Baltimore Beltway (I-695) intersection. Go 13 miles and take Columbia exit (MD Route 32 West). Go 2.5 miles and take Washington DC exit (US Route 29 South). Go 1.5 miles and take Johns Hopkins Road exit. APL is on the right about 0.5 mile. Turn right onto Pond Road, and follow 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, turn right onto Leishear Road. Go 0.8 mile, turn left onto Gorman Road. Go 0.7 mile, cross traffic circle and bridge over US Route 29. Road name changes to Johns Hopkins Road. APL is on the right about 0.5 mile. Turn right onto Pond Road, and follow signs to the Kossiakoff Center parking on the lower lot.

From US Route 29: Proceed on US 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 miles to Key West Avenue. Turn right at Key West Avenue and follow to first intersection. Make a left on Medical Center Drive. The Montgomery County Campus is on the right at 9601 Medical Center Drive.

From Interstate 70 (I-70): Take I-70 west to Md. Route 97 (Georgia Avenue). Turn left on Md. Route 97. Go south on Md. Route 97 to Norbeck Road (Md. Route 28). Turn right onto Norbeck Road. Continue west on Norbeck Road about 3.3 miles to East Gude Drive. Turn right onto East Gude Drive and proceed 4.3 miles across Rockville Pike (Md. Route 355) and Piccard Drive to Key West Avenue. Turn right on Key West Avenue. Cross Shady Grove Road and make a left at the first light onto Medical Center Drive. The Montgomery County Campus is on the right at 9601 Medical Center Drive.

From Washington, D.C. and Northern Virginia: Take the Beltway (I-495) to I-270 north, and 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 miles to Key West Avenue. Turn right at Key West Avenue and follow to first intersection. Make a left on Medical Center Drive. The Montgomery County Campus is on the right at 9601 Medical Center Drive.

Dorsey Student Services Center
From I-95 North or South: Exit I-95 towards Route 100 East. Exit Route 100 towards 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 JHU/Dorsey Center is on the second floor of the five-story high white building with blue windows.

From I-295 (Baltimore Washington Parkway) North or South: Exit I-295 towards Route 100 West. Exit Route 100 using the Coca-Cola Drive exit. Turn left onto Coca-Cola Drive towards 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 JHU/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. Blvd. 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 King Boulevard until it ends at Howard Street (remain in one of the middle lanes of King 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 I-295 (Baltimore-Washington Parkway) North or South: Exit I-295 towards Route 100 East. Exit Route 100 using the Coca-Cola Drive exit. Turn left onto Coca-Cola Drive towards 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 JHU/Dorsey Center is on the second floor of the five-story white building with blue windows.

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.
Directions and Maps

HEAT Center
From Baltimore and Washington, D.C. area: Take I-95 North to exit 85 Route 22 towards 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 Maryland 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 Maryland Route 4 south. At Solomons, cross the Thomas Johnson Bridge, and continue four miles to the stoplight at Maryland 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 Maryland 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 Maryland 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 D.C. 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 on the left-hand side. 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 3/4 of the way around until you reach the turn-off for Massachusetts Avenue (it is just one lane at first, alongside 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. Parking at Montgomery County Campus

Picking
Colonial parking – 1625 Mass. (202-295-8220)
This garage in the Washington Center is open from 7am until 8pm weekdays ONLY. While you cannot enter the garage after 8pm, you may exit at any time. The parking rate is $6 after 5:00pm; otherwise, it’s $7 per hour or $14 all day. Enter the garage from Massachusetts Ave. or 17th street. Since it is sometimes difficult to enter this garage at 5pm (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 am until 11:00pm. 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 after 5:00pm only weekdays.

Parking on Saturdays – 1333 New Hampshire Ave. (202-298-7076)
The closest parking garage, located at 1333 New Hampshire Avenue (entrance on 19th street), does not open until 9:00AM 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).
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Whiting School of Engineering
800-548-3647 or 410-516-7904 / Fax 410-516-7881

Please complete all sections of this form and return it to Engineering and Applied Science Programs for Professionals, Johns Hopkins University, 6810 Deerpath Road, Suite 100, Elkridge, Maryland 21075, along with your $75 application fee, made payable to Johns Hopkins University. You may pay by credit card using the Credit Card Authorization form. Official transcripts from all post-secondary institutions attended must be received by the Dorsey Student Services Center in the institution's sealed envelope. Unofficial transcripts cannot be accepted for admission.

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List any other names used on previous academic records ________________________________________________
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□ African American □ Asian American □ Hispanic □ Caucasian
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□ Applied Physics □ Photonics Option □ Materials and Condensed Matter Option
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□ Computer Science □ Telecommunications and Networking Option
□ Electrical and Computer Engineering □ Photonics Option □ Telecommunications and Networking Option
□ Environmental Engineering
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Reason for Charge: □ Application Fee ($75.00)
□ Graduation Fee ($100.00)
□ Late Tuition Payment Fee ($125.00)
□ Removal of Incomplete Grade Fee ($60.00)
□ Transfer Credit Fee ($260.00)
□ Tuition
□ Other ________________________________

Cardholder Signature: ___________________________________________ Date: ___________________

**Mailing Address:**

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