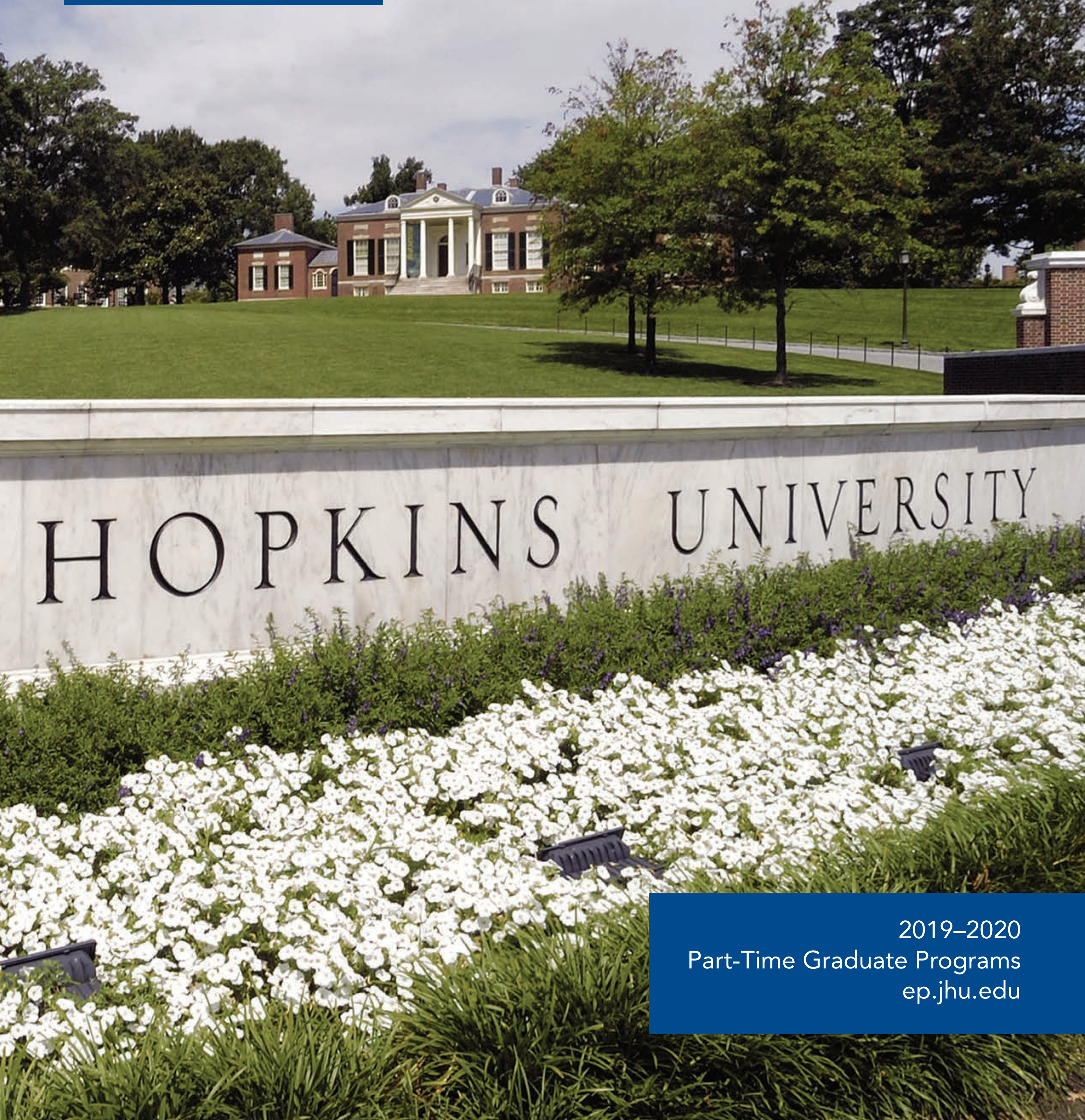
JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

Engineering for Professionals

Part-Time and Online Graduate Education in Engineering and Applied Sciences



2019–2020
Part-Time Graduate Programs
ep.jhu.edu

Dear Students,

The most successful engineers are those who never stand still when it comes to their education and their careers. Rather, it is those engineers who are committed to remaining at the forefront of their professions, who strive continuously to be well versed in the latest technologies, and who have the ability to continuously learn how their fields are evolving and which skills and knowledge are necessary to stay ahead of the curve who will achieve success.

At the Whiting School of Engineering, our Engineering for Professionals programs provide these motivated working engineers—in our region and around the world—with the tools and experiences necessary to enhance their education in ways that will have a direct positive impact on their professional lives.

We provide our engineering students with academic offerings of the highest quality, with all the value and prestige of a Johns Hopkins education. The breadth of our degree and certificate programs, the real-world experience of our faculty, and our state-of-the-art instructional methods enable us to provide students with unparalleled opportunities. At Engineering for Professionals, you will learn from experienced working professionals and outstanding academic faculty. These instructors speak directly to the applications of the course work you will study and continually improve and update content to encompass the very latest in both the theoretical understanding and applications in their areas of expertise.

In addition to the tremendous academic opportunities you will be afforded by enrolling in a Johns Hopkins Engineering for Professionals program, as a student here, you also will become part of a remarkable community. As a student and, later, as an alumnus, you will be a member of the uniquely successful Johns Hopkins family, connected forever to the traditions and achievements of one of the world's most esteemed academic research institutions.

Congratulations on choosing Johns Hopkins.

Sincerely,

Ed Schlesinger
Benjamin T. Rome Dean
Whiting School of Engineering

JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

Engineering for Professionals
Part-Time and Online Graduate Education
Academic Year 2019–2020

2019–2020 ACADEMIC CALENDAR

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

Important Semester Dates

	Summer 2019	**Fall 2019**	**Spring 2020**
First Day of Classes	May 28	August 26	January 27, 2020
Holidays	July 4	September 2; November 25–December 1	March 16–22, 2020
Graduation Application Deadlines	August 1	December 1	April 27, 2020
Last Day of Term	August 22	December 10	May 12, 2020
No classes on Tuesday, October 15, 2019, for the Fall Faculty Meeting.			

Registration Deadlines

	Summer 2019	**Fall 2019**	**Spring 2020**
Registration Opens	March 21	July 3	October 24
Final Day to Add	2nd Class Meeting	September 8	February 9, 2020
Final Day to Add Online Courses	June 12	September 11	February 12, 2020
Withdrawal/Audit Deadline	9th Class Meeting	November 8	March 31, 2020

Tuition Payment Deadlines*

	Summer 2019	**Fall 2019**	**Spring 2020**
	June 12	September 11	February 12, 2020

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

Whiting School of Engineering Graduation Ceremony is Tuesday, May 19, 2020.

University Commencement Day is Thursday, May 21, 2020.

CONTACT INFORMATION

Johns Hopkins Engineering for Professionals
3400 North Charles Street
Wyman Park Bldg, 3rd Floor West
Baltimore, MD 21218-2608
410-516-2300
ep.jhu.edu
jhep@jhu.edu

GENERAL INFORMATION AND REQUESTS

Admissions/Registration 410-516-2300

LOCATIONS

Applied Physics Laboratory 240-228-6510
Homewood Campus 410-516-8000
Southern Maryland Higher Education Center 301-737-2500

STUDENT SERVICES

Disability Services 410-516-2306
Financial Aid (146 Garland Hall) 410-516-8028
International Office 667-208-7001
Johns Hopkins Student Assistance Program 443-287-7000
Student Accounts (Johns Hopkins Engineering for Professionals) 410-516-8158
Student Accounts (Homewood) 410-516-8158
Transcripts (75 Garland Hall) 410-516-8080
University Registrar (75 Garland Hall) 410-516-8080
Veterans Certification (75 Garland Hall) 410-516-6635

ONLINE INFORMATION

Application .... ep.jhu.edu/apply
Catalog .... ep.jhu.edu/catalogs
Course Schedule .... ep.jhu.edu/schedule
Graduation Information .... ep.jhu.edu/graduation
Johns Hopkins Engineering for Professionals Forms .... ep.jhu.edu/student-forms

TEXTBOOKS

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

Information in this catalog is current as of publication in March 2019. For all updates, please visit ep.jhu.edu.

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

ENGINEERING ADMINISTRATION

WHITING SCHOOL OF ENGINEERING

T. E. SCHLESINGER
Benjamin T. Rome Dean

EDWARD SCHEINERMAN
Vice Dean, Graduate Education

HARRY K. CHARLES JR.
Associate Dean, Non-Residential Graduate Education

JOHNS HOPKINS ENGINEERING FOR PROFESSIONALS

DAN HORN
Associate Dean

PAUL HUCKETT
Assistant Dean, Learning Design and Innovation

MARY KAY LEMAY WAUGH
Assistant Dean, Marketing and Communications

MARIELLE NUZBACK
Senior Director of Operations

CHARISE BELL
Director, Marketing and Recruitment

NATHAN GRAHAM
Director, Center for Digital and Media Initiatives

TIM JARRETT
Director, Software Engineering

ABBY LATTES
Director, Communications

DOUG SCHILLER
Director, Admissions and Student Services

SANDRA ALTMAN
Admissions Manager

APPLIED PHYSICS LABORATORY EDUCATION CENTER

HARRY K. CHARLES JR.
Education Center Program Manager

CHRISTINE M. MORRIS
Partnership Manager

TRACY K. GAUTHIER
Education Center Operations Coordinator

GRADUATE PROGRAM CHAIRS

HEDY V. ALAVI
Program Chair, Environmental Engineering
Program Chair, Environmental Engineering and Science
Program Chair, Environmental Planning and Management

JAAFAR EL-AWADY
Program Chair, Mechanical Engineering

DAVID AUDLEY
Program Chair, Financial Mathematics

MICHAEL BETENBAUGH
Program Chair, Chemical and Biomolecular Engineering

PATRICK BINNING
Program Chair, Space Systems Engineering

HARRY K. CHARLES JR.
Program Chair, Applied Physics

TIMOTHY COLLINS
Program Chair, Engineering Management
Program Chair, Technical Management

EILEEN HAASE
Program Chair, Applied Biomedical Engineering

BRIAN K. JENNISON
Program Chair, Electrical and Computer Engineering

RONALD R. LUMAN
Program Chair, Systems Engineering

JOHN PIORKOWSKI
Program Co-Chair, Data Science
Program Chair, Information Systems Engineering

ALAN RAVITZ
Program Chair, Healthcare Systems Engineering

RACHEL SANGREE
Program Chair, Civil Engineering

JAMES C. SPALL
Program Chair, Applied and Computational Mathematics
Program Co-Chair, Data Science

JAMES SPICER
Program Chair, Materials Science and Engineering

LANIER WATKINS
Program Chair, Computer Science
Program Chair, Cybersecurity

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THE JOHNS HOPKINS DISTINCTION

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

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

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

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

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

WHITING SCHOOL OF ENGINEERING

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

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

GRADUATE PROGRAMS

Graduate students in the Johns Hopkins Engineering for Professionals (JHEP) program constitute one of the nation's largest student bodies in part-time engineering education at the master's-degree level. JHEP courses are continually updated for relevance, addressing industry trends and the latest advances in engineering and applied science fields. Most courses are offered online to afford working professionals the opportunity to advance their education at their convenience. Select courses are also offered on-site in the late afternoon or evening Monday through Thursday. Students receive individual attention from their advisors and instructors and benefit from small classes and well-equipped laboratory, computing, and classroom facilities.

Graduate students may take courses at any Hopkins location listed in the Degree and Certificates Offered chart on page 18. 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 Street, Philadelphia, PA 19104-2680; 215-662-5606. The Master of Science in Engineering in Systems Engineering program is accredited by the Engineering Accreditation Commission (EAC) of ABET, http://www.abet.org. Applicants need to hold a degree by a program accredited by the EAC of ABET in order to be admitted to the Master of Science in Engineering degree program. Students admitted without a Bachelor of Science degree from an EAC of ABET-accredited program or who did not complete the prerequisites that meet all of the EAC of ABET-accreditation requirements for attainment of student outcomes and for sufficient math, science, and engineering design at the Bachelor of Science level will receive a regionally accredited Master of Science degree.

DEGREES AND CERTIFICATES

The Johns Hopkins University offers a variety of degrees and certificates to 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 Biomedical Engineering, Applied and Computational Mathematics, Applied Physics, Computer Science, Cybersecurity, Data Science, Electrical and Computer Engineering, Engineering Management, Environmental Engineering and Science, Environmental Planning and Management, Financial Mathematics, Healthcare Systems Engineering, Information Systems Engineering, Space Systems Engineering, Systems Engineering, and Technical Management.

MASTER'S

Programs are offered in Chemical and Biomolecular Engineering, Civil Engineering, Environmental Engineering, Materials Science and Engineering, and Mechanical Engineering.

MASTER OF SCIENCE IN ENGINEERING

One program is offered in Systems Engineering.

JOINT DEGREE

A joint degree in Bioinformatics is offered by Johns Hopkins Engineering for Professionals and the Zanvyl Krieger School of Arts and Sciences Advanced Academic Programs. The description of this degree can be found in the Computer Science section on page 40. The administration is handled by the Zanvyl Krieger School of Arts and Sciences, and applications for admission to the Master of Science in Bioinformatics must be submitted directly to the Zanvyl Krieger School of Arts and Sciences at bioinformatics.jhu.edu.

POST-MASTER'S CERTIFICATE

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

GRADUATE CERTIFICATE

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

NON-DEGREE-SEEKING STUDENTS

Students who wish to enroll in courses but are not interested in pursuing a degree or certificate may enroll as Special Students.

ONLINE LEARNING

Johns Hopkins Engineering for Professionals has offered online courses since 2001, consistently delivering a unique educational experience that is both academically rigorous and highly practical. Johns Hopkins Engineering for Professionals' online programs complement the busy schedules of today's practicing engineers and scientists by allowing students to pursue studies face to face, online, or via a combination of both formats.

Courses are consistently being developed for online delivery. The following programs can be completed fully online:

- Applied Biomedical Engineering
- Applied and Computational Mathematics
- Applied Physics
- Civil Engineering
- Computer Science
- Cybersecurity
- Data Science
- Electrical and Computer Engineering
- Engineering Management
- Environmental Engineering
- Environmental Engineering and Science
- Environmental Planning and Management
- Financial Mathematics
- Healthcare Systems Engineering
- Information Systems Engineering
- Mechanical Engineering
- Space Systems Engineering
- Systems Engineering
- Technical Management

Our custom-built online programs and courses are designed using state-of-art technology and learning tools that create an interactive and engaging online learning experience. Delivered asynchronously, our online courses also include live synchronous time with the course instructor(s) and fellow students. Prospective and current students should consult ep.jhu.edu/online-learning for the current online course offerings, course schedules, and procedures for online programs.

ONLINE COURSE REGISTRATION

Online course registration adheres to the same schedule followed by on-site courses. Enrollment is granted on a first-come, first-served basis, and new and returning online students are strongly encouraged to register early. The deadline for adding online courses is two weeks after the first day of classes each term. See the 2019–2020 Academic Calendar on page ii for exact dates for each term.

VIRTUAL LIVE FORMAT

This format is a combined in-person and online course-delivery method. In-person class sessions are held synchronously with a virtual live session, serving local students as well as those students who are unable to attend in person but prefer a synchronous "live" class. The virtual student participates via a web-conferencing tool enabling two-way communication and live video feed with the in-person class.

ONLINE STUDENT SUPPORT SERVICES

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

ADMISSION REQUIREMENTS

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

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

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

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

MASTER'S DEGREE CANDIDATES

The program consists of ten courses planned in consultation with an advisor. General admission requirements for master's degree candidates are as follows: a bachelor's degree from a regionally accredited college or university (or a graduate degree in a technical discipline), or in the last semester of undergraduate study; a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies (when reviewing an application, the candidate's academic and professional background will be considered); a résumé detailing the applicant's professional background (only necessary for select programs; please consult individual program pages); official transcripts from all college studies; an application form submitted online; and any additional program-specific requirements.

After acceptance, each student is assigned an advisor with whom he or she may jointly design a program tailored to individual educational objectives.

Students must complete the master's degree within five years from the start of the first course applied to the program. Only one C-range grade (C+, C, or C–) can count toward the master's degree.

POST-MASTER'S CERTIFICATE CANDIDATES

To accommodate students who wish to pursue studies beyond the master's degree, many of the disciplines in the programs offer a certificate of post-master's study. This program is intended to add depth, breadth, or both in the discipline of the student's master's degree or a closely related one.

General admission requirements for post-master's certificate candidates are as follows: a master's degree in a relevant engineering or science discipline; a résumé detailing the applicant's professional background (only necessary for select programs; please consult individual program pages); official transcripts from all college studies; an application form submitted online; and any additional program-specific requirements.

After acceptance, each student is assigned an advisor with whom he or she may jointly design a program tailored to individual educational objectives.

Students must complete the post-master's certificate within three years from the start of the first course applied to the program. Only grades of B– or above can count toward the post-master's certificate.

GRADUATE CERTIFICATE CANDIDATES

The graduate certificate is offered in a select number of degree disciplines and is directed toward students who may not need a master's degree, may not have the opportunity to pursue the entire master's degree, or may wish to focus their studies on a set of courses in a specific subject area. The certificate generally consists of five to six courses. The program area of study specifies the selection and number of applicable courses.

General admission requirements for graduate certificate candidates are as follows: a bachelor's degree from a regionally accredited college or university (or a graduate degree in a technical discipline), or in the last semester of undergraduate study; a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies (when reviewing an application, the candidate's academic and professional background will be considered); a résumé detailing the applicant's professional background (only necessary for select programs; please consult individual program pages); official transcripts from all college studies; an application form submitted online; and any additional program-specific requirements.

After acceptance, each student is assigned an advisor with whom he or she jointly may design a program tailored to individual educational objectives.

Students must complete the graduate certificate within three years from the start of the first course applied to the program. Only grades of B– or above can count toward the graduate certificate.

LIFELONG LEARNING: SPECIAL STUDENTS

Qualified students who wish to enhance their knowledge, continue their education, and advance their careers through professional development, but who do not wish to commit to a master's degree or advanced certificate program, are welcome to take classes as special students in the Johns Hopkins Engineering for Professionals program. *Special students are non-degree seeking students who take courses at Johns Hopkins Engineering for Professionals.* If you take classes as a special student and later enroll in a master's degree program at EP, it is possible that the courses you took as a special student will apply to the degree.

General admission requirements for Special Students are as follows: a bachelor's degree from a regionally accredited college or university (or a graduate degree in a technical discipline), or in the last semester of undergraduate study; a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies (when reviewing an application, the candidate's academic and professional background will be considered); a résumé detailing the applicant's professional background (only necessary for select programs; please consult individual program pages); official transcripts from all college studies; an application form submitted online; and any additional program-specific requirements.

APPLICATION PROCEDURES

To be considered for admission to a degree or certificate program or to take courses as a Special Student, an applicant must submit an online application. The application is available online at ep.jhu.edu/apply. Complete instructions are available on the website.

An application for admission is not reviewed by an admissions committee until transcripts from all colleges attended are received and a résumé detailing the applicant's professional background is received (only necessary for select programs; please consult individual program pages). Once admitted, please note that official transcripts must be received in the institution's sealed envelope or sent electronically via the Scrip-Safe network. Failure to provide all official transcripts, a résumé (if necessary), and supporting documents will prevent future enrollment beyond the first semester. Please allow four to six weeks for application processing once all materials have been received.

READMISSION

An application is held on file for one year from the date of its receipt. Applicants who fail to submit required materials within this period may be asked to reapply.

Applicants must satisfy admission requirements in force at the time of reapplication. Admitted students may defer the start of their studies for up to one year after admission. After one year of inactivity, the student may be asked to 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 a Johns Hopkins Engineering for Professionals program establishes no claim or priority for admission to other divisions of the university.

INTERNATIONAL APPLICANTS

Johns Hopkins Engineering for Professionals is a mostly online program and, thus, 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 Office of International Services at Homewood at ois.jhu.edu.

INTERNATIONAL CREDENTIAL EVALUATION

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

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

ENGLISH PROFICIENCY

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

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

REQUESTS TO CHANGE PROGRAM OF STUDY

A student who wishes to change his/her status (e.g., from Special Student to master's degree candidate) or field of study (e.g., from Technical Management to Systems Engineering, or from the general Computer Science program to the Communications and Networking concentration) must send a written request to the Johns Hopkins Engineering for Professionals office at jhep@jhu.edu. The student must meet all the admission requirements of the new program.

REGISTRATION

Before registering for any engineering classes, each student must apply as a degree or certificate candidate or as a Special Student and must submit appropriate application materials for review. Application procedures are found in the Admission Requirements section on page 3. Applications are accepted on a continuing basis.

Payment of tuition is due by the specified deadline listed in the 2019–2020 Academic Calendar on page ii. Payment may be made by check, credit card, tuition remission, or company contract accompanied by purchase order. Johns Hopkins Engineering for Professionals does not defer payment for companies providing tuition reimbursement at the end of the term. In this instance, students must pay tuition themselves and be reimbursed by their employers. If payment is not made by the deadline date, a late payment fee of $150 will be incurred.

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

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

COURSE SCHEDULE

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

COURSE NUMBERING SYSTEM

All Whiting School of Engineering courses are numbered in the form 605.602, where

- 605 indicates the program—in this example, Computer Science; and
- 602 indicates the course number—in this example, Software Analysis and Design.

Courses with a zero before the first decimal point—e.g., 600.639—are daytime offerings of the Whiting School of Engineering departments.

Courses numbered xxx.1xx through xxx.5xx are undergraduate level and will not confer graduate credit.

COURSE CREDIT

All courses 600-level and above confer three graduate credit hours.

NEW APPLICANTS

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

INTERDIVISIONAL REGISTRATION

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

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

COURSE ENROLLMENT LIMITS

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

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

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

COURSE LOAD

Students who are employed full-time are advised not to take more than two courses per term without the permission of their academic advisor.

AUDITORS

Students may register as auditors with the approval of the appropriate program advisor. Although regular attendance is expected of auditors, they are exempt from quizzes, examinations, and other assigned work, and they receive no credit for the course. Students who are enrolled for credit but wish to become auditors must request this before the deadline listed for each term in the 2019–2020 Academic Calendar on page ii. There is no reduction in fees when auditing a course.

ADDING AND DROPPING COURSES

Courses may be added or dropped online at https://sis.jhu.edu. Deadlines for completing this procedure are given in the 2019–2020 Academic Calendar on page ii. Notification to the instructor does not constitute dropping a course. Students who stop attending a course without completing and submitting the drop form will receive an F grade. The refund policy pertaining to dropped courses is described in the Tuition and Fees section on page 12.

TEXTBOOKS

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

ACADEMIC REGULATIONS

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

Requirements for degree and certificate programs described in this catalog are subject to change. When this occurs, students may fulfill any set of requirements in force during their time in the program.

Note that only graduates who complete degree requirements prior to the ceremony date will be allowed to participate in Commencement activities.

ADVISORS AND DEGREE AUDIT

Students are assigned an advisor when accepted. In addition, students are strongly encouraged to contact their advisors prior to registration. Logging of course and program completion as well as viewing of approvals and exceptions approved by a student's advisor can be tracked through degree audit viewable through SIS.

ACADEMIC STANDING/CODE OF CONDUCT

The university reserves the right to exclude, at any time, a student whose academic standing or general conduct is deemed unsatisfactory. JHU students must abide by the JHU Code of Conduct found on page 11. It can also be found at https://studentaffairs.jhu.edu/policies-guidelines/student-code/.

MASTER'S DEGREE CANDIDATES

Only one C-range grade (C+, C, or C–) can count toward the master's degree.

Academic Probation—Any student receiving either one grade of D+, D, or 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. Students may attempt no more than two retakes during their program of study at JHEP; this may be on the same course or two different courses. If a grade of B– or above is earned in the repeated course, the probationary status will be removed. Please note that not all courses are offered every term. If an additional grade below B– is received before the course is repeated and successfully completed, the student will be dismissed. Dismissal appeals may be submitted to the JHEP Student Services Office.

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 receiving an additional grade of C+ or below
- Students receiving a grade of C(+/–) and a subsequent D+, D, or F
- Students receiving three grades of C(+/–)
- Students receiving two grades of D+, D, or F
- Students receiving grades of D+, D, or F and C(+/–) in the same term

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

POST-MASTER'S CERTIFICATE OR GRADUATE CERTIFICATE

No grade below B– can be counted toward a graduate certificate or post-master's certificate. The above policy for probation and dismissal will apply.

SPECIAL STUDENTS

The above policy for probation and dismissal applies to Special Students.

SECOND MASTER'S DEGREE

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

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

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

TIME LIMITATION

To be counted toward the degree or certificate, all coursework in the program must be completed within a specified period, which begins with the start of the first course applied to the student's program:

- Master's degree: five years
- Post-master's certificate: three years
- Graduate certificate: three years

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

LEAVE OF ABSENCE

Students who do not plan to enroll in classes for a period of more than one year must notify the Johns Hopkins Engineering 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 and are subject to the admission requirements in force at the date of the new application. Acceptance is not guaranteed even for students previously admitted. Courses taken prior to the interruption of studies will not count toward requirements if they are not completed within the time allowed for degree completion.

TRANSFERABILITY OF COURSES

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

TRANSFER COURSES

Requests to transfer courses from another institution toward the master's degree and certificate will be considered on an individual basis. A maximum of two Engineering for Professionals master's degree course requirements and one Engineering for Professionals certificate course requirement may be waived with documentation and approval of outside coursework. Any course considered for transfer must apply to the time limitation of the degree or certificate. All coursework in the program must be completed within a specified period, which begins with the start of the first course in the student's program; this includes any courses accepted for transfer. Transfer courses must be graduate-level, credit-bearing from an accredited institution, and directly applicable to the student's program of study at Johns Hopkins Engineering for Professionals.

For students who earned an undergraduate degree outside of the Whiting School of Engineering or the Krieger School of Arts and Sciences, coursework completed before the undergraduate degree was conferred can only be applied to a Whiting School of Engineering master's degree if evidence is provided by the degree-granting institution that the course was not applied to the undergraduate degree, and with advisor approval.

Continuing Education Unit (CEU) courses are not eligible for transfer. Requests should be submitted in writing to the Admissions Office. An official transcript and course description for the course to be transferred are both required. Requests to transfer courses cannot be processed if the transcript is not official. The fee for transfer is $440 per course.

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

WHITING SCHOOL OF ENGINEERING POLICY ON DOUBLE-COUNTING COURSES

The Whiting School of Engineering has established the following policies on double-counting coursework for all students in the full-time (Homewood) programs and the part-time Engineering for Professionals programs. If an individual program adopts double-counting policies more strict than these, the program's policies override the school-wide policies. Students are encouraged to refer to individual program policies.

BACHELOR'S–MASTER'S DOUBLE COUNTING COURSEWORK APPLIED TO A BACHELOR'S DEGREE

Students either in a Whiting School of Engineering combined (bachelor's/master's) program or seeking a Whiting School of Engineering master's degree after having earned a Whiting School of Engineering or Krieger School of Arts and Sciences bachelor's degree may double-count two courses (graduate-level) to both programs with the permission of the master's faculty advisor. Whiting School of Engineering master's degree candidates may not double-count courses applied to a bachelor's degree earned at a different institution. Individual graduate programs reserve the right to enforce stricter policies.

COURSEWORK NOT APPLIED TO A BACHELOR'S DEGREE

For students who either are in a Whiting School of Engineering combined bachelor's/master's degree program or have already earned a Whiting School of Engineering or Krieger School of Arts and Sciences bachelor's degree and are seeking a Whiting School of Engineering master's degree, any graduate-level coursework (as defined by the Whiting School of Engineering graduate program) not applied to the undergraduate degree may be applied to the graduate degree, regardless of when that course was taken (i.e., before or after the undergraduate degree has been conferred) with the permission of the master's faculty advisor.

For students who earned an undergraduate degree outside of the Whiting School of Engineering or the Krieger School of Arts and Sciences, coursework completed before the undergraduate degree was conferred can only be applied to a Whiting School of Engineering master's degree if evidence is provided by the degree-granting institution that the course was not applied to the undergraduate degree, and with advisor approval.

MASTER'S–MASTER'S DOUBLE COUNTING COURSEWORK APPLIED TO A MASTER'S DEGREE

Students pursuing (1) a Whiting School of Engineering master's and a master's from any JHU school simultaneously, (2) a Whiting School of Engineering master's after having earned a master's from any JHU school, or (3) a Whiting School of Engineering master's degree after having earned a master's degree from another institution, may double-count either two semester-length courses or three quarter-length courses across two master's programs, as long as the courses are equivalent to the graduate-level or higher in Whiting School of Engineering full-time graduate programs. The student must receive approval from both master's degree program faculty advisors if both sets of degree requirements will be completed at the same time. For a student to double-count coursework from two master's degrees whose requirements are met at different times, the student must obtain only the approval of the faculty advisor in the program to be finished second. Individual graduate programs reserve the right to enforce stricter policies.

TIMING AND RAMIFICATIONS FOR CURRENT STUDENTS

This policy will be applied to all students entering a Whiting School of Engineering master's program in fall 2007 and beyond. Any student who has entered a Whiting School of Engineering master's program before then will be exempt from this policy and should follow the course arrangement made with his/her advisor, provided it is in compliance with departmental, school, and university requirements.

DECLARATION OF DOUBLE-COUNTED COURSE

Whiting School of Engineering master's students wishing to double-count courses must submit these courses to the Whiting School of Engineering master's program for approval. If it is learned that a student has double-counted a course for the Whiting School of Engineering master's degree without permission of the Whiting School of Engineering master's program, this program reserves the right to revoke the degree.

DOUBLE-COUNTING ACROSS THREE OR MORE PROGRAMS

With bachelor's-master's and master's-master's double-counting, across any number of degree programs, a student can reduce the number of master's courses required by up to two (with approval of the programs involved). Beyond that, the remaining courses must be unique to the degree program. With a ten-course master's degree program, for example, eight of those courses must be unique to the program and not applied to a different degree at any level. A student can double-count any number of undergraduate courses to the various master's degrees (but at most, two to each master's program), and he/she can double-count the same course across any number of degrees pursued (again, with the approval of the programs involved).

GRADUATION

Note that only graduates who complete degree requirements prior to the ceremony date will be allowed to participate in Commencement activities.

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

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

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

Commencement information is sent the first week in March. To receive their diplomas, students must pay all student accounts in full and resolve all outstanding charges of misconduct and violations of academic integrity. Students will receive an e-bill notification in the spring from Student Accounts. The e-bill will be sent to the student's preferred e-mail account. For graduation fees, see the Tuition and Fees section on page 12. Johns Hopkins University diplomas indicate the school (e.g., Whiting School of Engineering), degree, and major (e.g., Master of Science-Computer Science) without identifying the student's focus area/track.

HONORS

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

GRADING SYSTEM

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

A grade of F indicates the student's failure to complete or comprehend the coursework. A course for which an unsatisfactory grade (C+ through F) has been received may be retaken. The original grade is replaced with an R. If the failed course includes laboratory work, both the lecture and laboratory work must be retaken unless the instructor indicates otherwise. A grade of W is issued to those who have dropped the course after the refund period (the sixth class meeting for on-site courses) but before the drop deadline.

The transcript is part of the student's permanent record at the university. No grade may be changed except to correct an error, to replace an incomplete with a grade, or to replace a grade with an R.

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

INCOMPLETES

A grade of incomplete (I) is assigned when a student fails to complete a course on time for valid reasons, usually under circumstances beyond his or her control.

Conditions for resolving an incomplete are established by the instructor. A final grade must be submitted to the Registrar within four weeks after the start of the following term. A grade of F will be assigned if the incomplete work is not submitted by the deadline. For academic year 2019–2020, the dates by which final grades for incomplete work must be resolved are as follows:

Summer term	September 25
Fall semester	February 19
Spring semester	June 24

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 Johns Hopkins Engineering for Professionals Student Services staff if their names are reported so they can take corrective action. These early reports are for the benefit of students and their advisors and are not part of the permanent record.

Grades are available online at https://sis.jhu.edu/sswf. These reports cannot be requested by telephone or personal inquiry. Students with questions regarding their grade reports or who want their transcripts sent to other institutions should make arrangements with the Office of the Registrar, 410-516-8080 or web.jhu.edu/registrar.

GRADE APPEALS

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

STUDENT ATTENDANCE

Students are expected to regularly attend all courses in which they are enrolled. Although Johns Hopkins Engineering for Professionals 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 Johns Hopkins Engineering for Professionals staff to inform students of the cancellation, a makeup time for the class (if available), and information regarding assignments. If an instructor informs the Johns Hopkins Engineering for Professionals office of a class cancellation with enough lead time, students will be contacted.

ACADEMIC MISCONDUCT

This section summarizes the Homewood and Engineering for Professionals Graduate Academic Misconduct Policy that can be found at https://ep.jhu.edu/wseacademicmisconductpolicy.

THE ROLES OF STUDENTS AND FACULTY

Academic misconduct by graduate students is unacceptable. It is the responsibility of all graduate students to adhere to strict standards of integrity in their professional and scholarly activities, as well as to high standards of conduct in their nonacademic activities, and students are encouraged to report known or suspected acts of misconduct. It is the responsibility of the faculty and other supervisors of scholarly activities to monitor carefully the academic and other scholarly activities of graduate students under their supervision and to subject these activities to rigorous evaluation.

PROCEDURES FOR RESOLVING

If a student is suspected of academic misconduct, the faculty member responsible for the course in which the misconduct allegedly occurred must review the facts of the case promptly with the student. If, after speaking with the student and any witnesses, the faculty member believes that academic misconduct has occurred, the faculty member must immediately contact their Academic Integrity Officer or designee to (a) determine whether the offense is a first offense or a subsequent offense, and (b) review the options and procedures available under this policy.

COPYRIGHT VIOLATIONS

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

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

COMPUTER USAGE

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

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

Please visit it.jhu.edu 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

A full year of graduate tuition in the Whiting School of Engineering is found at jhu.edu/admissions/tuition. With support from the dean of the Whiting School of Engineering, our students enjoy a substantially decreased out-of-pocket cost. The typical tuition rates for Engineering for Professionals courses during the 2019–2020 academic year are $1,200 (undergraduate/200-level) and $4,440 (graduate/600-level and higher). If you need a receipt for the courses you are taking, please contact Student Accounts at 410-516-8158. Please contact our admissions staff with any questions.

GRADUATION FEE

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

LATE TUITION PAYMENT FEE

Tuition payment due dates are indicated in the 2019–2020 Academic Calendar on page ii. If payment is received after the due date, a late payment fee of $150 will be incurred.

TRANSFER CREDIT FEE

Graduate courses completed at another school and approved for transfer are assessed a fee of $440 per course.

REFUND POLICY

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

Drop Date	Refund
On-Site Courses	
Prior to third class meeting	100%
Prior to fourth class meeting	75%
Prior to fifth class meeting	50%
Prior to sixth class meeting	25%
Online Courses	
Prior to third week of class	100%
Prior to fourth week of class	75%
Prior to fifth week of class	50%
Prior to sixth week of class	25%

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 the Return of Title IV Funds Policy section on page 230 for further information.

FINANCIAL AID

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

DEFINITION OF FULL-TIME, HALF-TIME, AND PART-TIME ENROLLMENT

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

VETERANS BENEFITS

Johns Hopkins is approved by the Maryland Higher Education Commission for the training of veterans and the widows and children of deceased veterans under provisions of the various federal laws pertaining to veterans' educational benefits. Information about veterans' benefits and enrollment procedures may be obtained at the Registrar's Office, Garland Hall, 410-516-6635. 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 (DVA) on a monthly basis. The amount of reimbursement is determined by the veteran's number of dependents and course load.

INITIAL ENROLLMENT

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

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

Johns Hopkins University
Office of the Registrar-75 Garland Hall
Veterans Affairs
3400 N. Charles Street
Baltimore, MD 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 the DVA at gibill.va.gov and 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 that 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 (add/drops) that might affect the amount of their monthly payment from the DVA. Failure to do so will cause the DVA to seek restitution from the veteran for the overpayment of benefits.

STANDARDS OF PROGRESS

Continuation of DVA payments is dependent on 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.

YELLOW RIBBON TUITION ASSISTANCE PROGRAM

Johns Hopkins Engineering for Professionals participates in the Yellow Ribbon program provided by the DVA to eligible veterans. For more specific information on applying for the Yellow Ribbon program at Johns Hopkins Engineering for Professionals, please contact the Registrar's Office at web.jhu.edu/registrar or 410-516-6635.

FACILITIES AND STUDENT SERVICES

Johns Hopkins Engineering for Professionals courses are offered throughout Maryland at the Homewood campus in Baltimore; the Applied Physics Laboratory (APL) in Laurel; and the Southern Maryland Higher Education Center in St. Mary's County; as well as Virtual Live and online. Student services are provided at the Student Services Center located in Baltimore, Maryland. The educational and student facilities and services provided at each location are described on the following pages.

STUDENT ID JCARDS

The JCard acts as the university library card, which enables students to check out books from the Homewood Eisenhower Library or at any of the campus center libraries and provides access to many computer laboratories. To order or replace a lost or stolen JCard, contact the JCard Office at 410-516-5121.

TRANSCRIPTS

Official transcripts will be mailed at no charge on written request of the student. Requests for transcripts should be directed to the Office of the Registrar, 410-516-8080. Transcripts may also be ordered online, for a fee, from iwantmytranscript.com. For more information about each of these options, see web.jhu.edu/registrar/transcripts.

SERVICES FOR STUDENTS WITH DISABILITIES

Johns Hopkins University is committed to creating a welcoming and inclusive environment for students, faculty, staff, and visitors with disabilities. Consequently, we work to ensure that students, employees, and visitors with disabilities have equal access to university programs, facilities, technology, and web properties.

Students are strongly encouraged to initiate requests for accommodation with the disability coordinator in their respective schools as early in the semester as possible. As part of the interactive process, together with the Director, ADA Compliance and Disability Services, requests are reviewed to determine appropriate accommodations on a case-by-case basis. All information provided by the student to the disability coordinator during the intake process will be considered along with the student's documentation.

Students with disabilities who anticipate barriers to full participation in courses and/or campus activities are encouraged to contact the Services Coordinator for Johns Hopkins Engineering for Professionals by phone or by e-mail.

Disability Services Coordinator
Engineering for Professionals
Johns Hopkins University
Wyman Park Building
3400 N. Charles Street
Baltimore, MD 21218
Website: https://ep.jhu.edu/student-services/other-services/disability-services
E-mail: ep-disability-svcs@jhu.edu
Phone: 410-516-2306

The Director, ADA Compliance and Disability Services, serves as the central point of contact for the review of accommodation requests, information on physical and programmatic access, resolution of complaints and problems, faculty and staff concerns, and identification of available recourses.

Director
ADA Compliance and Disability Services
Office of Institutional Equity
Johns Hopkins University
Wyman Park Building, Suite 515
3400 N. Charles Street
Baltimore, MD 21218
Website: http://accessibility.jhu.edu/
E-mail: oiedisability@jhu.edu
Phone: 410-516-8075

JH STUDENT ASSISTANCE PROGRAM

The Johns Hopkins Student Assistance Program (JHSAP) is a professional counseling service that can assist students with managing problems of daily living. JHSAP focuses on problem solving through short-term counseling. Accessing the service requires only a phone call to arrange an appointment with a counselor. To meet the needs of our students, offices are conveniently located in the Washington/Baltimore corridor. Online students may call one of the following numbers for consultation and will be directed to the appropriate resource or office. To contact JHSAP, call 443-997-7000 or toll-free 866-764-2317. Additional information regarding the JHSAP services can be obtained at jhsap.org. JHSAP services are completely confidential. The program operates under state and federal confidentiality legislation and is HIPAA (Health Insurance Portability and Accountability Act) compliant.

INCLEMENT WEATHER

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

WEB-BASED STUDENT DIRECTORY

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

COMPUTERS

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

OFFICE 365 E-MAIL

Office 365 provides Johns Hopkins University students with a free 25-GB lifetime e-mail account; a 25-GB online storage solution; collaboration, blogging, photo-sharing, event-planning, and instant-messaging tools and more. Some features of Office 365 for Education include:

- Built-in protection and anytime/anywhere access
- A 25-GB e-mail account built on Outlook Live, permitting up to 20-MB attachments
- Easy access to e-mail from a variety of browsers on both the PC and Mac, including full support for Internet Explorer, Firefox, and Safari
- Connection to mailboxes using POP3, IMAP4 with preferred e-mail program or mobile phones
- Capabilities such as address books, calendars, mobile push e-mail, instant messaging, and more
- Improved collaboration and productivity, with ease of finding and sharing data and schedules from anywhere
- Ability to look up other users in the address book
- A single inbox to access all important communications

All students are required to activate their assigned Office 365 e-mail address. All official communications from Johns Hopkins Engineering for Professionals and Johns Hopkins University will be sent to this address, including class assignments, billing information, emergency notifications, and other important items. Visit it.johnshopkins.edu/services/email/office365 to find instructions to activate your Office 365 e-mail address and to forward your Johns Hopkins University e-mail to other addresses.

JHBOX

JHBox is a web-based utility intended to provide students with a personal, easy-to-use interface to upload, download, and share files to users both inside and outside of the institution. Some features of JHBox include:

- 50 GB of FREE space per user
- Ease of uploading content, organizing documents, sharing links, managing files, and setting permissions
- Ability to designate files as private
- Version history for up to 90 days
- JHED ID login

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

JHPULSE

JHPulse is a remote-access application that provides access to restricted Hopkins applications and systems when you are not on campus. JHPulse offers greater compatibility and support for newer computers and their operating systems.

Remote access to Hopkins is provided by JHPulse online through the myJH portal. More information about JHPulse is available at it.johnshopkins.edu/services/network/VPN.

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

ANTI-VIRUS POLICY

All devices vulnerable to electronic viruses must be appropriately safeguarded against infection and retransmission. It is the responsibility of every user to ensure that antivirus protection is current and effectively implemented. Infected devices may be blocked, removed, or both from the Johns Hopkins Network by IT@JH or appropriate departmental personnel. Visit it.johnshopkins.edu/antivirus to find the antivirus protection that is appropriate for your personal and Johns Hopkins University-owned computer.

LOCATIONS

See the Directions and Maps section on page 233 for more information on the various Education Centers.

APPLIED PHYSICS LABORATORY EDUCATION CENTER

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

One of APL's most significant educational contributions is its close collaboration with Johns Hopkins Engineering for Professionals. Chairs for twelve of Johns Hopkins Engineering for Professionals' twenty-one programs hold staff positions at APL, along with nearly half of Johns Hopkins Engineering for Professionals' instructors. APL provides classrooms, conference space, classroom labs, and UNIX/Linux servers for administrative and academic support of Johns Hopkins Engineering for Professionals in the Kossiakoff Center and Montpelier 7 (MP7).

COMPUTERS AND LAB FACILITIES

Computer facilities at the Kossiakoff Center include Multi-User UNIX and Linux systems that support designated courses. Students can access these systems or the JHU network from their personal computers using either the wireless network within the Kossiakoff Center and

MP7 or their own personal network connections. The Engineering and Computing Lab and the Instructional Computer Lab provide support for general-purpose computing and applications development, embedded systems development and testing with state-of-the-art measurement equipment, interface design, and computer/network security.

In addition to classrooms and computer labs, MP7 houses the Computer Robotics Lab, which allows students to develop computer-controlled autonomous robots. The center is also the site of 3-D printer capabilities and the Johns Hopkins Engineering for Professionals' Microwave and Electronics Laboratory and an Advanced Communication Laboratory, which are state-of-the-art facilities for designing, developing, and testing microwave chips and communication circuits. These laboratories house a full variety of microwave testing and measurement equipment including:

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

In support of the microwave chip and circuit design process, our CAD laboratory has workstations offering the latest versions of following software:

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

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

PARKING

Parking tags are not required. The lower-level parking lot near the Kossiakoff Center is recommended when visiting the Kossiakoff Center. Ample parking is available near the Engineering for Professionals entrance to MP7.

REMOTE LABS

Johns Hopkins Engineering for Professionals also offers remote access to advanced test equipment for online courses that include a hardware lab component. Students can log into the remote labs at any time during the week to complete their lab assignments using equipment such as oscilloscopes, spectrum analyzers, power supplies, and function generators.

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

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

TEXTBOOKS

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

JOHNS HOPKINS MERCHANDISE

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

HOPKINS STUDENT UNION

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

SECURITY SERVICES

A daily escort van service is available during the hours of 5:00 p.m.–3:00 a.m. to pick up and deliver students to any campus parking lot or other location within a one-mile radius of campus. Vans leave every half hour from the Eisenhower Library.

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

Emergency telephone stands with blue lights, which connect directly with the security office, are located at strategic locations around campus. These telephones open a direct line to the security office as soon as the receiver is lifted or the button pushed. To ward off a possible attacker, an alarm sounds at the phone. Pay telephones also are available in most campus buildings. Security officers patrol parking lots from 3:00 to 11:00 p.m., Monday through Friday. Student monitors, wearing bright orange vests and carrying radios, patrol the upper and lower quads during fall and spring semesters.

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

PARKING

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

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, nine colleges and universities are participating, offering over eighty academic programs. Facilities include two buildings with classrooms, computer labs, a learning conference room, two student lounges, vending areas, and interactive videoconferencing capability. Building III is expected to open in fall 2020 and will add sixteen classrooms to SMHEC's academic resources as well as include educational offerings and research in air, ground, and underwater autonomous systems. The Systems Engineering program is offered here.

DEGREES AND CERTIFICATES OFFERED

Program	Degree and Certificate	Focus Areas/Tracks	Locations	Online Offerings
Applied Biomedical Engineering 585.XXX	Master of Science in Applied Biomedical Engineering	▪ Imaging ▪ Instrumentation ▪ Translational Tissue Engineering	▪ Applied Physics Laboratory ▪ Homewood Campus	**Can Be Completed Online***
	Post-Master's Certificate			
Applied and Computational Mathematics 625.XXX	Master of Science in Applied and Computational Mathematics	▪ Applied Analysis ▪ Information Technology and Computation ▪ Operations Research ▪ Probability and Statistics ▪ Simulation and Modeling	▪ Applied Physics Laboratory	**Can Be Completed Online**
	Post-Master's Certificate			
Applied Physics 615.XXX	Master of Science in Applied Physics	*CONCENTRATIONS* ▪ Materials and Condensed Matter ▪ Photonics	▪ Applied Physics Laboratory	**Can Be Completed Online**
	Post-Master's Certificate			
Chemical and Biomolecular Engineering 545.XXX	Master of Chemical and Biomolecular Engineering	▪ Biotechnology ▪ Nanotechnology	▪ Homewood Campus	**Not Currently Available**
Civil Engineering 565.XXX	Master of Civil Engineering	▪ Structural Engineering	▪ Applied Physics Laboratory ▪ Homewood Campus	**Can Be Completed Online**
	Graduate Certificate			
Computer Science 605.XXX	Master of Science in Computer Science	▪ Bioinformatics ▪ Cybersecurity ▪ Data Communications and Networking ▪ Data Science and Cloud Computing ▪ Database Systems and Knowledge Management ▪ Enterprise and Web Computing ▪ Human–Computer Interaction and Visualization ▪ Software Engineering ▪ Systems ▪ Theory *CONCENTRATION* ▪ Communications and Networking	▪ Applied Physics Laboratory	**Can Be Completed Online**
	Post-Master's Certificate			

**The degree requirements for the Master of Science in Applied Biomedical Engineering include a two-weekend lab and clinical residency in Baltimore.*

Program	Degree and Certificate	Focus Areas/Tracks	Locations	Online Offerings
Cybersecurity 695.XXX	Master of Science in Cybersecurity	▪ Analysis ▪ Networks ▪ Systems	▪ Applied Physics Laboratory	**Can Be Completed Online**
	Post-Master's Certificate			
Data Science 685.XXX	Master of Science in Data Science		▪ Applied Physics Laboratory	**Can Be Completed Online**
	Post Master's Certificate			
Electrical and Computer Engineering 525.XXX	Master of Science in Electrical and Computer Engineering	▪ Communications and Networking ▪ Computer Engineering ▪ Electronics and the Solid State ▪ Optics and Photonics ▪ RF and Microwave Engineering ▪ Signal Processing ▪ Systems and Control *CONCENTRATIONS* ▪ Communications and Networking ▪ Photonics	▪ Applied Physics Laboratory	**Can Be Completed Online**
	Post-Master's Certificate			
	Graduate Certificate			
Engineering Management 595.XXX	Master of Engineering Management	*CONCENTRATIONS* ▪ Applied Biomedical Engineering ▪ Applied and Computational Mathematics ▪ Applied Physics ▪ Communications, Controls, and Signal Processing ▪ Computer Engineering ▪ Computer Science ▪ Cybersecurity ▪ Information Systems Engineering ▪ Materials Science and Engineering ▪ Mechanical Engineering ▪ Optics and Photonics ▪ RF and Microwave Engineering ▪ Structural Engineering	▪ Applied Physics Laboratory	**Can Be Completed Online***
Environmental Engineering 575.XXX	Master of Environmental Engineering	▪ Environmental and Occupational Health		**Only Available Online**
	Post-Master's Certificate			
	Graduate Certificate			
	Certificate in Environmental and Occupational Health			

**The Master of Engineering Management can be completed fully online depending on which concentration you choose.*

Program	Degree and Certificate	Focus Areas/Tracks	Locations	Online Offerings
Environmental Engineering and Science 575.XXX	Master of Science in Environmental Engineering and Science	▪ Environmental and Occupational Health		Only Available Online
	Post-Master's Certificate			
	Graduate Certificate			
	Certificate in Environmental and Occupational Health			
Environmental Planning and Management 575.XXX	Master of Science in Environmental Planning and Management	▪ Environmental and Occupational Health		Only Available Online
	Post-Master's Certificate			
	Graduate Certificate			
	Certificate in Environmental and Occupational Health			
Financial Mathematics 555.XXX	Master of Science in Financial Mathematics			Can Be Completed Online
	Graduate Certificate in Financial Risk Management			
	Graduate Certificate in Quantitative Portfolio Management			
	Graduate Certificate in Securitization			
Healthcare Systems Engineering 655.XXX	Master of Science in Healthcare Systems Engineering			Only Available Online
Information Systems Engineering 635.XXX	Master of Science in Information Systems Engineering	▪ Cybersecurity ▪ Data Engineering ▪ Enterprise and Web Computing ▪ Human–Computer Interaction ▪ Information Management ▪ Network Engineering ▪ Software Engineering ▪ Systems Engineering	▪ Applied Physics Laboratory	Can Be Completed Online
	Post-Master's Certificate			
	Graduate Certificate			
Materials Science and Engineering 515.XXX	Master of Materials Science and Engineering	▪ Biotechnology ▪ Nanomaterials *CONCENTRATION* ▪ Nanotechnology	▪ Applied Physics Laboratory ▪ Homewood Campus	Not Currently Available

Program	Degree and Certificate	Focus Areas/Tracks	Locations	Online Offerings
Mechanical Engineering 535.XXX	Master of Mechanical Engineering	▪ Manufacturing ▪ Solids/Mechanics of Materials ▪ Thermofluids ▪ Robotics and Controls	▪ Applied Physics Laboratory ▪ Homewood Campus	**Can Be Completed Online**
	Post-Master's Certificate			
Space Systems Engineering 675.XXX	Master of Science in Space Systems Engineering	▪ Technical Systems/ Subsystems ▪ Leadership/ Management	▪ Applied Physics Laboratory	**Can Be Completed Online***
Systems Engineering 645.XXX	Master of Science in Systems Engineering	▪ Systems ▪ Cybersecurity ▪ Human Systems ▪ Modeling and Simulation ▪ Project Management ▪ Software Systems	▪ Applied Physics Laboratory ▪ Southern Maryland Higher Education Center	**Can Be Completed Online**
	Master of Science in Engineering in Systems Engineering			
	Post-Master's Certificate			
	Graduate Certificate			
Technical Management 595.XXX	Master of Science in Technical Management	▪ Organizational Management ▪ Project Management ▪ Project/Organizational Management ▪ Quality Management ▪ Technical Innovation Management	▪ Applied Physics Laboratory	**Can Be Completed Online**
	Post-Master's Certificate			
	Graduate Certificate			

**The degree requirements for the Master of Science in Space Systems Engineering include a weekend residency at the Applied Physics Laboratory.*

APPLIED BIOMEDICAL ENGINEERING

- **Master of Science in Applied Biomedical Engineering**
  Focus Areas: Imaging; Instrumentation; or Translational Tissue Engineering*
- **Post-Master's Certificate in Applied Biomedical Engineering**

The part-time Applied Biomedical Engineering program aims to educate and train practicing scientists and engineers to be able to carry out engineering-oriented research and development in the biomedical sciences. In addition to diverse student backgrounds, the program's most valuable strength lies in the active faculty currently involved in research and development.

Courses are offered at the Applied Physics Laboratory, Homewood campus, and online. Various electives are offered through the full-time Department of Biomedical Engineering and the School of Medicine.

PROGRAM COMMITTEE

EILEEN HAASE, PROGRAM CHAIR
Senior Lecturer, Biomedical Engineering
JHU Whiting School of Engineering

BROCK WESTER, VICE PROGRAM CHAIR
Senior Professional Staff
JHU Applied Physics Laboratory

ANIL MAYBHATE
Lecturer, Applied Biomedical Engineering
JHU Whiting School of Engineering

LARRY SCHRAMM
Professor of Biomedical Engineering
Johns Hopkins School of Medicine

ARTIN SHOUKAS
Professor Emeritus
Johns Hopkins School of Medicine

LESLIE TUNG
Professor of Biomedical Engineering
Johns Hopkins School of Medicine

A focus area must be chosen for this program.

REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include the following prerequisites: (1) mathematics, through ordinary differential equations; (2) calculus-based physics, including mechanics, heat and energy, electricity and magnetism, and elementary quantum concepts; (3) chemistry; and (4) molecular biology. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering (all prerequisites beyond calculus are available) or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Transcripts from all college studies must be submitted. When reviewing an application, the candidate's academic and professional background will be considered.

Courses in organic chemistry, molecular biology, mathematics, and signals and systems are offered for those who may need them to satisfy the eligibility requirements or to refresh their knowledge.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students are required to choose a focus area to follow. The curriculum consists of five core courses (one from the focus area), at least one additional course from the focus area, and four electives (at least four of the ten courses must be at the 700-level or higher). One elective may be substituted for a required course if the student has previously completed an equivalent graduate-level course or can demonstrate competency. Electives may be from the Applied Biomedical Engineering (585.xxx) program, or from the Department of Biomedical Engineering (580.xxx) in the full-time program and the Zanvyl Krieger School of Arts and Sciences' Advanced Academic Programs (410.xxx). Students may take courses from other programs following approval by the Applied Biomedical Engineering chair or vice chair. All course selections are subject to advisor approval.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post-Master's Certificate in Applied Biomedical Engineering.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least five of the six courses must be from the Applied Biomedical Engineering (585.xxx) program, and at least two of the courses must be at the 700-level. Students are allowed to take one elective course. Courses from the full-time program and/or medical school (580.xxx) may be substituted. Only grades of B– and above may count toward the post-master's certificate. Focus areas are not available for students pursuing certificates. All course selections are subject to advisor approval.

COURSES

PREREQUISITE COURSES

525.202 Signals and Systems OR
625.260 Introduction to Signals and Systems
585.207 Molecular Biology OR
410.602 Molecular Biology*
625.201 General Applied Mathematics

Applicants whose prior education does not include the prerequisites listed under Admission Requirements may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. All prerequisite courses beyond calculus are available at Johns Hopkins Engineering. These courses do not count toward the degree or certificate requirements.

CORE COURSES

585.601 Physiology for Applied Biomedical Engineering I
585.602 Physiology for Applied Biomedical Engineering II
585.615 Mathematical Methods for Applied Biomedical Engineering OR
535.641 Mathematical Methods for Engineers
585.625 Biomedical Engineering Practice and Innovation

See below for the fifth core course, which is specific to each focus area.

COURSES BY FOCUS AREAS

The focus areas offered represent related groups of courses that are relevant for students with interests in the selected areas. Students are required to choose a focus area to fol-

* *This course is offered online through the Zanvyl Krieger School of Arts and Sciences' Advanced Academic Programs.*

low. The focus areas are presented as an aid to students in planning their course schedules and are only applicable to students seeking a master's degree. They do not appear as official designations on a student's transcript or diploma.

IMAGING

CORE COURSE

585.704 Principles of Medical Imaging

OTHER COURSES FOR THE FOCUS AREA (SELECT AT LEAST ONE)

585.616 Principles of Medical Instrumentation and Devices
585.703 Applied Medical Image Processing
585.710 Biochemical Sensors
585.732 Advanced Signal Processing for Biomedical Engineers
585.741 MR Imaging in Medicine

INSTRUMENTATION

CORE COURSE (SELECT ONE)

585.613 Medical Sensors and Devices
585.616 Principles of Medical Instrumentation and Devices

OTHER COURSES FOR THE FOCUS AREA (SELECT AT LEAST ONE)

585.617 Rehabilitation Engineering
585.724 Neural Prosthetics: Science, Technology, and Applications
585.732 Advanced Signal Processing for Biomedical Engineers
585.734 Biophotonics
585.747 Advances in Cardiovascular Medicine
585.781 Frontiers in Neuroengineering
585.783 Introduction to Brain-Computer Interfaces

TRANSLATIONAL TISSUE ENGINEERING

CORE COURSE

585.729 Cell and Tissue Engineering

OTHER COURSES FOR THE FOCUS AREA (SELECT AT LEAST ONE)

585.617 Rehabilitation Engineering
585.708 Biomaterials
585.709 Biomechanics of Cell and Stem Cells
585.710 Biochemical Sensors
585.720 Orthopedic Biomechanics
585.726 Biomimetics in Biomedical Engineering
585.747 Advances in Cardiovascular Medicine
585.751 Immunoengineering

ELECTIVES

The following electives are offered during the day through the full-time Department of Biomedical Engineering at the Homewood campus or at the School of Medicine.

525.786 Human–Robotics Interaction
580.420 Build-a-Genome
580.430 Systems Pharmacology and Personalized Medicine
580.448 Biomechanics of the Cell
580.451 Cellular and Tissue Engineering Laboratory
580.452 Cellular and Tissue Engineering Laboratory
580.466 Statistical Methods in Imaging
580.488 Foundations of Computational Biology and Bioinformatics II
580.495 Microfabrication Laboratory
580.616 Introduction to Linear Systems
580.625 Structure and Function of the Auditory and Vestibular Systems
580.626 Structure and Function of the Auditory and Vestibular Systems
580.628 Topics in Systems Neuroscience
580.630 Theoretical Neuroscience
580.632 Ionic Channels in Excitable Membranes
580.634 Molecular and Cellular Systems Physiology Laboratory
580.639 Models of the Neuron
580.641 Cellular Engineering
580.642 Tissue Engineering
580.673 Magnetic Resonance in Medicine
580.677 Advanced Topics in Magnetic Resonance
580.682 Computational Models of the Cardiac Myocyte
580.684 Ultrasound Imaging: Theory and Applications
580.688 Foundations of Computation Biology and Bioinformatics II
580.691 Learning Theory
580.771 Principles of Design of Biomedical Instrumentation
585.613 Medical Sensors and Devices
585.616 Principles of Medical Instrumentation and Devices
585.617 Rehabilitation Engineering
585.619 Regulation of Medical Devices
585.623 Systems Bioengineering Lab I (1/2 credit)
585.627 Systems Bioengineering Lab II (1/2 credit)
585.703 Applied Medical Image Processing
585.704 Principles of Medical Imaging
585.708 Biomaterials
585.709 Biomechanics of Cell and Stem Cells
585.710 Biochemical Sensors
585.720 Orthopedic Biomechanics
585.724 Neural Prosthetics: Science, Technology, and Applications
585.726 Biomimetics in Biomedical Engineering
585.729 Cell and Tissue Engineering
585.732 Advanced Signal Processing for Biomedical Engineers
585.734 Biophotonics

585.741 MR Imaging in Medicine
585.747 Advances in Cardiovascular Medicine
585.751 Immunoengineering
585.761 Bioentrenpreneurship
585.781 Frontiers in Neuroengineering
585.783 Introduction to Brain-Computer Interfaces
585.800 Independent Study I
585.801 Independent Study II
605.653 Computational Genomics
605.656 Computational Drug Discovery and Development
605.754 Analysis of Gene Expression and High-Content Biological Data
605.755 Systems Biology

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

APPLIED AND COMPUTATIONAL MATHEMATICS

- **Master of Science in Applied and Computational Mathematics**
  Focus Areas: Applied Analysis; Information Technology and Computation; Operations Research; Probability and Statistics; and Simulation and Modeling*
- **Post-Master's Certificate in Applied and Computational Mathematics**

The part-time Applied and Computational Mathematics program prepares working professionals through instruction in mathematical and computational techniques that are fundamentally important and practically relevant. Students may choose from one of five optional focus areas, or may tailor their courses to meet individual needs.

Courses are offered at the Applied Physics Laboratory and online.

PROGRAM COMMITTEE

JAMES C. SPALL, PROGRAM CHAIR
Principal Professional Staff
JHU Applied Physics Laboratory

Research Professor, Department of
Applied Mathematics and Statistics
JHU Whiting School of Engineering

BERYL CASTELLO, PROGRAM COORDINATOR
Senior Lecturer, Department of
Applied Mathematics and Statistics
JHU Whiting School of Engineering

STACY D. HILL
Senior Professional Staff
JHU Applied Physics Laboratory

GEORGE NAKOS
Professor (retired), Mathematics
US Naval Academy

EDWARD R. SCHEINERMAN
Professor, Applied Mathematics and Statistics

Vice Dean for Graduate Education
JHU Whiting School of Engineering

J. MILLER WHISNANT
Principal Professional Staff
JHU Applied Physics Laboratory

**A focus area is not required for this program.*

REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include the following prerequisites: (1) at least one mathematics course beyond multivariate calculus (such as advanced calculus, differential equations, or linear algebra); and (2) familiarity with at least one programming language (e.g., C, C++, FORTRAN, Java, Python, R, or MATLAB). Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering or, with approval, at another regionally accredited institution. In addition to these requirements, a detailed work résumé, statement of purpose, and transcripts from all college studies must be submitted. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of four core courses (including a two-term 700-level course sequence) and six electives. The six electives must include at least four from the program (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 core sequences (625.717/718, 625.721/722, and 625.725/726). An independent study (625.800), research project (625.801–802), or thesis (625.803–804) may be substituted for one or two of the 700-level courses outside of the 700-level core sequence. Overall, given the requirements above, at least four 700- or 800-level ACM courses (625.xxx) must be completed. A student who has taken at least one semester of graduate statistics (outside of Applied and Computational Mathematics) may substitute another 625.xxx course for 625.603 with approval of the student's advisor. The prior statistics course must be calculus-based and must cover the same general topics as 625.603. Focus areas are not required for this program. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

Selected undergraduate-level courses are also offered to provide mathematical background for the program. These 100- and 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 prior education.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in applied and computational mathematics or a closely related technical discipline are eligible to apply for the Post-Master's Certificate in Applied and Computational Mathematics. It is required that applicants have completed courses equivalent to 625.603 Statistical Methods and Data Analysis, and at least one of 625.601 Real Analysis or 625.609 Matrix Theory in prior graduate coursework (in or out of the prior master's degree).

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least four of the six courses must be from the Applied and Computational Mathematics program and numbered 625.680 or higher. At least three of these courses must be at the 700- or 800-level, and 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. Courses 625.601 Real Analysis, 625.603 Statistical Methods and Data Analysis, and 625.609 Matrix Theory may not be counted toward the certificate. An independent study (625.800), research project (625.805–806), or thesis (625.807–808) may be substituted for one or two of the 700-level courses outside of the 700-level core sequence. Only grades of B– or above can count toward the post-master's certificate. All course selections are subject to advisor approval.

STUDENTS SEEKING A DOCTORAL DEGREE

JHU offers both a PhD and a D.Eng. Students with a long-term interest in pursuing a PhD through the Applied Mathematics and Statistics (AMS) Department in the full-time program should coordinate their course plans with their Applied and Computational Mathematics advisor and with a representative in the AMS Department. Certain courses within Applied and Computational Mathematics may be especially helpful in passing the required entrance examination for the PhD program. Priority of admission is not given to graduates of the Applied and Computational Mathematics program for the PhD program. Students interested in the D.Eng. should contact the program chair or program coordinator.

COURSES

UNDERGRADUATE-LEVEL COURSES

625.108 Calculus I

625.109 Calculus II

625.201 General Applied Mathematics

625.250 Multivariable and Complex Analysis

625.251 Introduction to Ordinary and Partial Differential Equations

625.260 Introduction to Signals and Systems

Students may take selected courses above as desired (e.g., as a refresher) or as required via provisional admissions status. Applicants whose prior education does not include the prerequisites listed under Admission Requirements may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. The courses above do not count toward the degree or certificate requirements.

CORE COURSES

625.603 Statistical Methods and Data Analysis

625.601 Real Analysis OR
625.609 Matrix Theory

SELECT ONE SEQUENCE

625.717 Advanced Differential Equations: Partial Differential Equations AND
625.718 Advanced Differential Equations: Nonlinear Differential Equations and Dynamical Systems (courses may be taken in either order)

625.721 Probability and Stochastic Process I AND
625.722 Probability and Stochastic Process II

625.725 Theory of Statistics I AND
625.726 Theory of Statistics II

COURSES BY FOCUS AREAS

The focus areas offered represent related groups of courses that are relevant for students with interests in the selected areas. The focus areas are presented as an aid to students in planning their course schedules and are generally applicable to students seeking a master's degree; the more advanced courses within each focus area may also apply to the post-master's certificate. Focus areas are not required for this program. They do not appear as official designations on a student's transcript or diploma.

APPLIED ANALYSIS

625.601 Real Analysis

625.602 Modern Algebra

625.604 Ordinary Differential Equations

625.609 Matrix Theory

625.611 Computational Methods

625.680 Cryptography

625.685 Number Theory

625.687 Applied Topology

625.690 Computational Complexity and Approximation

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 Theory of Probability

625.800 Independent Study in Applied and Computational Mathematics

625.801 Applied and Computational Mathematics Master's Research AND
625.802 Applied and Computational Mathematics Master's Research

625.803 Applied and Computational Mathematics Master's Thesis AND
625.804 Applied and Computational Mathematics Master's Thesis

625.805 Applied and Computational Mathematics Post-Master's Research AND
625.806 Applied and Computational Mathematics Post-Master's Research

625.807 Applied and Computational Mathematics Post-Master's Thesis AND
625.808 Applied and Computational Mathematics Post-Master's Thesis

INFORMATION TECHNOLOGY AND COMPUTATION

625.603 Statistical Methods and Data Analysis

625.609 Matrix Theory

625.611 Computational Methods

625.615 Introduction to Optimization

625.616 Optimization in Finance

625.617 Introduction to Enumerative Combinatorics

625.623 Introduction to Operations Research: Probabilistic Models

625.633 Monte Carlo Methods

625.638 Neural Networks

625.661 Statistical Models and Regression

625.665 Bayesian Statistics

625.680 Cryptography

625.685 Number Theory

625.687 Applied Topology

625.690 Computational Complexity and Approximation

625.695 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 Modeling, Simulation, and Monte Carlo
625.800 Independent Study in Applied and Computational Mathematics
625.801 Applied and Computational Mathematics Master's Research AND
625.802 Applied and Computational Mathematics Master's Research
625.803 Applied and Computational Mathematics Master's Thesis AND
625.804 Applied and Computational Mathematics Master's Thesis
625.805 Applied and Computational Mathematics Post-Master's Research AND
625.806 Applied and Computational Mathematics Post-Master's Research
625.807 Applied and Computational Mathematics Post-Master's Thesis AND
625.808 Applied and Computational Mathematics Post-Master's Thesis

OPERATIONS RESEARCH

625.603 Statistical Methods and Data Analysis
625.609 Matrix Theory
625.615 Introduction to Optimization
625.616 Optimization in Finance
625.617 Introduction to Enumerative Combinatorics
625.623 Introduction to Operations Research: Probabilistic Models
625.633 Monte Carlo Methods
625.636 Graph Theory
625.641 Mathematics of Finance: Investment Science
625.642 Mathematics of Risk, Options, and Financial Derivatives
625.661 Statistical Models and Regression
625.662 Design and Analysis of Experiments
625.663 Multivariate Statistics and Stochastic Analysis
625.664 Computational Statistics
625.665 Bayesian Statistics
625.690 Computational Complexity and Approximation
625.695 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
625.741 Game Theory
625.743 Stochastic Optimization and Control
625.744 Modeling, Simulation, and Monte Carlo
625.800 Independent Study in Applied and Computational Mathematics
625.801 Applied and Computational Mathematics Master's Research AND
625.802 Applied and Computational Mathematics Master's Research
625.803 Applied and Computational Mathematics Master's Thesis AND
625.804 Applied and Computational Mathematics Master's Thesis
625.805 Applied and Computational Mathematics Post-Master's Research AND
625.806 Applied and Computational Mathematics Post-Master's Research
625.807 Applied and Computational Mathematics Post-Master's Thesis AND
625.808 Applied and Computational Mathematics Post-Master's Thesis

PROBABILITY AND STATISTICS

625.603 Statistical Methods and Data Analysis
625.617 Introduction to Enumerative Combinatorics
625.620 Mathematical Methods for Signal Processing
625.623 Introduction to Operations Research: Probabilistic Models
625.633 Monte Carlo Methods
625.638 Neural Networks
625.641 Mathematics of Finance: Investment Science
625.642 Mathematics of Risk, Options, and Financial Derivatives
625.661 Statistical Models and Regression
625.662 Design and Analysis of Experiments
625.663 Multivariate Statistics and Stochastic Analysis
625.664 Computational Statistics
625.665 Bayesian Statistics
625.680 Cryptography
625.690 Computational Complexity and Approximation
625.692 Probabilistic Graphical Models
625.695 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
625.728 Theory of Probability
625.734 Queuing Theory with Applications to Computer Science
625.740 Data Mining
625.741 Game Theory
625.743 Stochastic Optimization and Control

625.744 Modeling, Simulation, and Monte Carlo
625.800 Independent Study in Applied and Computational Mathematics
625.801 Applied and Computational Mathematics Master's Research AND
625.802 Applied and Computational Mathematics Master's Research
625.803 Applied and Computational Mathematics Master's Thesis AND
625.804 Applied and Computational Mathematics Master's Thesis
625.805 Applied and Computational Mathematics Post-Master's Research AND
625.806 Applied and Computational Mathematics Post-Master's Research
625.807 Applied and Computational Mathematics Post-Master's Thesis AND
625.808 Applied and Computational Mathematics Post-Master's Thesis

SIMULATION AND MODELING

625.603 Statistical Methods and Data Analysis
625.604 Ordinary Differential Equations
625.615 Introduction to Optimization
625.616 Optimization in Finance
625.620 Mathematical Methods for Signal Processing
625.623 Introduction to Operations Research: Probabilistic Models
625.633 Monte Carlo Methods
625.638 Neural Networks
625.641 Mathematics of Finance: Investment Science
625.642 Mathematics of Risk, Options, and Financial Derivatives
625.661 Statistical Models and Regression
625.662 Design and Analysis of Experiments
625.663 Multivariate Statistics and Stochastic Analysis
625.664 Computational Statistics
625.665 Bayesian Statistics
625.690 Computational Complexity and Approximation
625.695 Time Series Analysis and Dynamic Modeling
625.714 Introductory Stochastic Differential Equations with Applications
625.717 Advanced Differential Equations: Partial Differential Equations
625.718 Advanced Differential Equations: Nonlinear Differential Equations and Dynamical Systems
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
625.728 Theory of Probability
625.740 Data Mining
625.741 Game Theory
625.743 Stochastic Optimization and Control
625.744 Modeling, Simulation, and Monte Carlo
625.800 Independent Study in Applied and Computational Mathematics
625.801 Applied and Computational Mathematics Master's Research AND
625.802 Applied and Computational Mathematics Master's Research
625.803 Applied and Computational Mathematics Master's Thesis AND
625.804 Applied and Computational Mathematics Master's Thesis
625.805 Applied and Computational Mathematics Post-Master's Research AND
625.806 Applied and Computational Mathematics Post-Master's Research
625.807 Applied and Computational Mathematics Post-Master's Thesis AND
625.808 Applied and Computational Mathematics Post-Master's Thesis

ELECTIVES

Two electives may be from the Applied and Computational Mathematics program or from another graduate program provided the courses have significant mathematical content. Electives from outside of the program must be approved by an advisor.

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

APPLIED PHYSICS

- **Master of Science in Applied Physics**
  Concentrations: Materials and Condensed Matter or Photonics*
- **Post-Master's Certificate in Applied Physics**

The part-time Applied Physics program bridges the gap between pure physics and engineering by providing courses and independent study options covering a wide variety of technical and scientific phenomena. Working professionals develop skills appropriate for their careers in technical research or advanced graduate study. One of the program's strengths is its faculty, who are primarily drawn from the Johns Hopkins Applied Physics Laboratory and government agencies, and other universities. Faculty interests are in materials, ocean sciences, optics, solid-state physics, sensors, and space sciences.

Courses are offered at the Applied Physics Laboratory and online.

PROGRAM COMMITTEE

HARRY K. CHARLES JR., PROGRAM CHAIR
Principal Professional Staff
JHU Applied Physics Laboratory

WILLIAM E. TORRUELLAS, VICE PROGRAM CHAIR
Principal Professional Staff
JHU Applied Physics Laboratory

DAVID L. PORTER
Principal Professional Staff
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ABIGAIL M. RYMER
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JENNIFER L. SAMPLE
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JHU Applied Physics Laboratory

JAMES B. SPICER
Program Chair, Materials Science and Engineering
Professor, Materials Science & Engineering
JHU Whiting School of Engineering

MICHAEL E. THOMAS
Principal Professional Staff
JHU Applied Physics Laboratory

**A concentration is not required for this program.*

REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to a graduate program of study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include (1) mathematics through vector analysis and ordinary differential equations; (2) general physics; (3) modern physics; (4) intermediate mechanics; and (5) intermediate electricity and magnetism. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in their undergraduate studies. Transcripts from all college studies must be submitted. When reviewing an application, the candidate's academic and professional background will be considered. A résumé is optional.

The intermediate mechanics and intermediate electricity and magnetism requirements may be waived if the applicant has an exceptional academic record and a strong background in mathematics.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of four core courses and six electives. At least four of the courses must be at the 700-level or higher. An elective may be substituted for a required course if the student has previously completed an equivalent graduate-level course. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

CONCENTRATIONS

MATERIALS AND CONDENSED MATTER

Students can elect to concentrate their studies in materials and condensed matter by completing a combination of courses from the Applied Physics (615.xxx), Electrical and Computer Engineering (525.xxx), and Materials Science and Engineering (515.xxx) programs. Applied Physics students specializing in materials and condensed matter must complete three of the core courses plus 615.680 Materials Science.

Of the remaining six courses, four or more must be materials and condensed matter courses selected from the Applied Physics (615.xxx), Electrical and Computer Engineering (525.xxx), and Materials Science and Engineering (515.xxx) programs. All course selections are subject to advisor approval.

Concentrations are noted on the student's transcript.

PHOTONICS

Three Applied Physics core courses (615.xxx), one Electrical and Computer Engineering core course (525.xxx), four Photonics electives, and two electives from the program must be completed. All course selections are subject to advisor approval.

Concentrations are noted on the student's transcript.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post-Master's Certificate in Applied Physics.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least four of the six courses must be from the Applied Physics program (615.xxx), and at least two of the courses must be at the 700-level. Students are allowed to take two electives (at least one must be at the 700-level). Only grades of B– or above can count toward the post-master's certificate. All course selections are subject to advisor approval.

COURSES

CORE COURSES

SELECT FOUR (AT LEAST THREE MUST BE FROM THE FIRST SIX)

615.641 Mathematical Methods for Physics and Engineering
615.642 Electromagnetics
615.651 Statistical Mechanics and Thermodynamics
615.653 Classical Mechanics
615.654 Quantum Mechanics
615.665 Modern Physics
615.671 Principles of Optics
615.680 Materials Science

ELECTIVES

SELECT SIX

615.611 Classical Physics
615.621 Electric Power Principles
615.644 Fundamentals of Space Systems and Subsystems I
615.645 Fundamentals of Space Systems and Subsystems II
615.646 Physics of Magnetism

615.647 Fundamentals of Sensors
615.648 Alternate Energy Technology
615.662 Introduction to Astrophysics
615.681 Polymeric Materials
615.731 Photovoltaic and Solar Thermal Energy Conversion
615.744 Fundamentals of Space Systems and Subsystems I
615.745 Fundamentals of Space Systems and Subsystems II
615.746 Nanoelectronics: Physics and Devices
615.747 Sensors and Sensor Systems
615.748 Introduction to Relativity
615.751 Modern Optics
615.753 Plasma Physics
615.755 Space Physics
615.757 Solid-State Physics
615.758 Modern Topics in Applied Optics
615.760 Physics of Semiconductor Devices
615.761 Introduction to Oceanography
615.762 Applied Computational Electromagnetics
615.765 Chaos and Its Applications
615.769 Physics of Remote Sensing
615.772 Cosmology
615.775 Physics of Climate
615.778 Computer Optical Design
615.780 Optical Detectors and Applications
615.781 Quantum Information Processing
615.782 Optics and MATLAB
615.800 Applied Physics Project
615.802 Directed Studies in Applied Physics

COURSES BY CONCENTRATION

MATERIALS AND CONDENSED MATTER

FOUR CORE COURSES

615.641 Mathematical Methods for Physics and Engineering
615.642 Electromagnetics
615.651 Statistical Mechanics and Thermodynamics
615.680 Materials Science

ELECTIVES (SELECT AT LEAST FOUR)

510.606 Chemical and Biological Properties of Materials*
515.617 Nanomaterials
515.635 Mechanical Properties of Materials
525.606 Electronic Materials
525.621 Introduction to Electronics and the Solid State
615.646 Physics of Magnetism
615.647 Fundamentals of Sensors
615.681 Polymeric Materials
615.746 Nanoelectronics: Physics and Devices
615.747 Sensors and Sensor Systems
615.757 Solid-State Physics
615.760 Physics of Semiconductor Devices

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 materials science and condensed matter.

PHOTONICS

FOUR CORE COURSES (THE THREE 615.XXX COURSES ARE REQUIRED)

525.613 Fourier Techniques in Optics
525.625 Laser Fundamentals
525.691 Fundamentals of Photonics
615.641 Mathematical Methods for Physics and Engineering
615.654 Quantum Mechanics
615.671 Principles of Optics

ELECTIVES (SELECT AT LEAST FOUR)

525.613 Fourier Techniques in Optics
525.625 Laser Fundamentals
525.636 Optics and Photonics Laboratory
525.691 Fundamentals of Photonics
525.753 Laser Systems and Applications
525.756 Optical Propagation, Sensing, and Backgrounds
525.772 Fiber-Optic Communication Systems
525.796 Introduction to High-Speed Optoelectronics
525.797 Advanced Fiber Optic Laboratory
615.751 Modern Optics
615.758 Modern Topics in Applied Optics
615.778 Computer Optical Design
615.780 Optical Detectors and Applications
615.781 Quantum Information Processing
615.782 Optics and MATLAB

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.

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

** 510.xxx courses are offered through the full-time Department of Materials Science & Engineering.*

CHEMICAL AND BIOMOLECULAR ENGINEERING

- **Master of Chemical and Biomolecular Engineering**
  Focus Areas: Biotechnology or Nanotechnology*

The part-time Chemical and Biomolecular Engineering program allows working professionals to choose from two focus areas, or to study a more traditional curriculum that is supplemented with electives from related engineering fields, the basic sciences, or mathematics. The program offers a professional, non-thesis curriculum for working engineers, but is also suited for those with a science background who are taking their career in a new direction.

Courses are offered at the Homewood campus. Various electives are offered through the full-time Department of Chemical & Biomolecular Engineering.

PROGRAM COMMITTEE

MICHAEL BETENBAUGH, PROGRAM CHAIR
Professor, Department of Chemical
& Biomolecular Engineering
JHU Whiting School of Engineering

KONSTANTINOS KONSTANTOPOULOS
Chair, Department of Chemical
& Biomolecular Engineering
JHU Whiting School of Engineering

**A focus area is not required for this program.*

REQUIREMENTS

MASTER'S

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include the following prerequisites: (1) a bachelor's degree in chemical engineering, or a closely related technical or scientific discipline; (2) mathematics through differential and integral calculus and differential equations; and (3) coursework in physical chemistry and thermodynamics. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering (all prerequisites beyond calculus are available) or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Transcripts from all college studies must be submitted. When reviewing an application, the candidate's academic and professional background will be considered.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students may count 400-level courses toward their degree if the course is not offered at the 600-level and if the department offering the course considers it to be graduate-level. Courses offered at both the 400- and 600-levels must be taken at the higher level. At least six of the ten courses must be from the Chemical and Biomolecular Engineering program. Exceptions to this must be approved by the program chair. A course from any other program may be allowed to count as one of the six courses only if it has significant chemical and biomolecular engineering content and is consistent with the student's educational goals. Nine of the courses (including the Chemical and Biomolecular Engineering courses) must be STEM related. The tenth course may be chosen from any field of interest to the student. Focus areas are not required for this program. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All other grades must be B– or above. All course selections are subject to advisor approval.

COURSES

PREREQUISITE COURSES

545.203 Engineering Thermodynamics
545.204 Applied Physical Chemistry
545.301 Kinetic Processes
545.303 Transport Phenomena I
545.304 Transport Phenomena II
550.291 Linear Algebra & Differential Equations*

Applicants whose prior education does not include the prerequisites listed under Admission Requirements may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. All prerequisite courses beyond calculus are available at Johns Hopkins Engineering. These courses do not count toward the degree or certificate requirements.

Undergraduate courses from other engineering or science disciplines may be substituted if there is significant overlap in material. Permission to substitute or waive course requirements will be at the discretion of the program chair.

RECOMMENDED CORE COURSES

545.602 Metabolic Systems Biotechnology
545.604 Transport Phenomena in Practice
545.615 Interfacial Science with Applications to Nanoscale Systems
545.671 Advanced Thermodynamics and Kinetics in Practice
545.673 Advanced Chemical Reaction Engineering in Practice

FOCUS AREAS

Students should work with an advisor to choose an appropriate selection of courses in keeping with their desired focus area (Biotechnology or Nanotechnology) and career goals. Focus areas do not appear as official designations on a student's transcript or diploma.

ADDITIONAL REPRESENTATIVE COURSES

Additional relevant courses are available from Chemical and Biomolecular Engineering and other related majors. The following are presented as aid to students in planning their class schedules. The students are encouraged to seek out other courses of relevance to the Master's degree.

ELECTIVES

410.601 Advanced Biochemistry†
410.602 Molecular Biology†
410.603 Advanced Cell Biology I†
410.645 Biostatistics†
520.772 Advanced Integrated Circuits‡
545.603 Colloids and Nanoparticles
545.606 Chemical and Biomolecular Separation

**550.xxx courses are offered through the full-time Department of Applied Mathematics & Statistics.*

† 410.xxx courses are offered through the part-time Zanvyl Krieger School of Arts and Sciences' Advanced Academic Programs.

‡ 520.xxx courses are offered through the full-time Department of Electrical & Computer Engineering.

545.614 Computational Protein Structure Prediction and Design
545.615 Interfacial Science with Applications to Nanoscale Systems
545.619 Project in Design: Alternative Energy
545.621 Project in Design: Pharmacodynamics
545.622 Introduction to Polymeric Materials
545.628 Supramolecular Materials and Nanomedicine
545.630 Thermodynamics and Statistical Mechanics
545.637 Application of Molecular Evolution to Biotechnology
545.639 Advanced Topics in Pharmacokinetics and Pharmacodynamics
545.640 Micro- and Nanotechnology
545.652 Advanced Transport Phenomena
545.660 Polymer Physics
545.662 Polymer Design and Bioconjugation
545.665 Engineering Principles of Drug Delivery
545.668 Introduction to Nonlinear Dynamics and Chaos
545.672 Green Engineering, Alternative Energy and CO_2 Capture/Sequestration
545.691 Chemical Engineering Modeling and Design for Graduate Students
545.800 Independent Study
580.632 Ionic Channels in Excitable Membranes[§]
585.708 Biomaterials
585.709 Biomechanics of Cell and Stem Cells
585.710 Biochemical Sensor

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

[§]580.xxx courses are offered through the full-time Biomedical Engineering Department.

CIVIL ENGINEERING

- **Master of Civil Engineering**
  Focus Area: Structural Engineering*
- **Graduate Certificate in Civil Engineering**

The part-time Civil Engineering program provides graduate instruction in the fields of structural engineering, geotechnical engineering, coastal engineering, and preservation engineering. Students in the program may choose to focus their studies in structural engineering or to pursue a general civil engineering course of study.

Structural engineering courses are primarily available online, while other courses are offered at the Homewood Campus.

PROGRAM COMMITTEE

RACHEL H. SANGREE, PROGRAM CHAIR
Lecturer, Civil Engineering
JHU Whiting School of Engineering

LUCAS DE MELO
Senior Engineer
Geosyntec Consultants

Adjunct Professor, Civil Engineering
JHU Whiting School of Engineering

LORI GRAHAM-BRADY
Department Chair, Civil Engineering
JHU Whiting School of Engineering

JOHN MATTEO
Partner
1200 Architectural Engineers, PLLC

Lecturer, Civil Engineering
JHU Whiting School of Engineering

**A focus area is not required for this program.*

REQUIREMENTS

MASTER'S

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study as outlined in the Admission Requirements section on page 3. The applicant's prior education must include a degree in civil engineering or a closely related technical discipline. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Transcripts from all college studies must be submitted. When reviewing an application, the candidate's academic and professional background will be considered.

Applicants without a degree in civil engineering may be accepted to the program provided they demonstrate the successful completion of coursework from a regionally accredited institution including: Calculus I, Calculus II, Linear Algebra and Differential Equations, Physics I, Statics, Mechanics of Materials, Theory of Structures, and Soil Mechanics. Further, such applicants are advised that Design of Steel Structures and Design of Reinforced Concrete Structures are prerequisites for many of the structural engineering elective courses in the program.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. The courses required depend on the course of study selected by the student. Students may pursue a general civil engineering course of study or choose to focus their studies in structural engineering. Note that focus areas do not appear on a student's transcript, but are used for advising and course planning.

The general civil engineering program requires three core courses: 535.641 Mathematical Methods for Engineers; 565.606 Geotechnical Engineering Principles; and 565.604 Structural Mechanics. Four additional courses must be chosen from the list of civil engineering electives, and the remaining three courses may be selected from any of the civil engineering (e.g., 565.XXX) offerings. A maximum of one course may be selected from outside of civil engineering (this does not include the courses outside of civil engineering listed as electives).

The structural engineering focus area is designed to provide students with the necessary background and technical skills required of professional structural engineers. Students pursuing this focus area are required to take 535.641 Mathematical Methods for Engineers and 565.604 Structural Mechanics. Five additional courses must be chosen from the list of structural engineering electives, and the remaining three courses may be selected from any of the civil engineering (e.g. 565.xxx) offerings. A maximum of one course may be selected from outside of civil engineering (this does not include the courses outside of civil engineering listed as electives).

Any deviations from these requirements must be approved by the program chair.

GRADUATE CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate-level courses, but not necessarily interested in pursuing a full master's degree are eligible for the Graduate Certificate in Civil Engineering. Admission requirements for the Graduate Certificate in Civil Engineering are the same as those for the Master of Civil Engineering.

Once matriculated, if a student should later decide to pursue the full master's degree, all successfully completed courses will apply provided they meet program requirements and that the remaining courses to be completed fall within a five-year time limit. The student must declare their intention prior to completing the certificate.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Each student will work with the program chair to design a program tailored to meet their individual goals. Focus areas are not available for students pursuing certificates. All course selections are subject to advisor approval.

COURSES

GENERAL CIVIL ENGINEERING

CORE COURSES

535.641 Mathematical Methods for Engineers
565.604 Structural Mechanics
565.606 Geotechnical Engineering Principles

ELECTIVES

(SELECT AT LEAST FOUR)

565.608 BIM Applications in Civil Engineering
565.658 Natural Disaster Risk Modeling
565.664 Advanced Foundation Design
565.680 Marine Geotechnical Engineering
565.682 Design of Ocean Structures
565.684 Port and Harbor Engineering
565.686 Sustainable Coastal Engineering
565.762 Ground Improvement Methods
565.764 Retaining Structures and Slope Stability
575.626 Hydrogeology

575.629 Modeling Contaminant Migration through Multimedia Systems
575.703 Environmental Biotechnology
565.800 Independent Study in Civil Engineering
565.801 Independent Study in Civil Engineering

The Civil Engineering electives represent courses in the areas of coastal, geotechnical, and preservation engineering.

COURSES BY FOCUS AREA

A focus area is not required for this program and it does not appear as an official designation on a student's transcript or diploma. Rather, the focus area is provided as a tool to aid students in planning their course schedules in preparation to enter a specific field within civil engineering after graduation.

The Structural Engineering focus area was designed by the Civil Engineering Program Committee to prepare students for careers in structural engineering. Students who do not identify with structural engineering may work with their advisor to select a broad yet cohesive group of courses to make up a general program of study in Civil Engineering (see above).

STRUCTURAL ENGINEERING

CORE COURSES

535.641 Mathematical Methods for Engineers
565.604 Structural Mechanics

ELECTIVES (SELECT AT LEAST FIVE)

565.608 BIM Applications in Civil Engineering
565.616 Applied Finite Element Methods
565.619 Advanced Structural Analysis
565.620 Advanced Steel Design
565.622 Advanced Reinforced Concrete Design
565.623 Bridge Design and Evaluation
565.626 Design of Wood Structures
565.628 Preservation Engineering I: Theory and Practice
565.630 Prestressed Concrete Design
565.631 Preservation Engineering II: Theory and Practice
565.633 Investigation, Diagnosis, and Rehabilitation
565.636 Lateral Forces: Analysis and Design of Building Structures
565.637 Preservation Engineering in the Urban Context
565.682 Design of Ocean Structures
565.731 Structural Dynamics
565.732 Earthquake Engineering
565.734 Wind Engineering

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

COMPUTER SCIENCE

- **Master of Science in Computer Science**
  Concentrations: Communications and Networking
  Tracks: Bioinformatics; Cybersecurity; Data Communications and Networking; Data Science and Cloud Computing; Database Systems and Knowledge Management; Enterprise and Web Computing; Human–Computer Interaction and Visualization; Software Engineering; Systems; or Theory*
- **Post-Master's Certificate in Computer Science**

The part-time Computer Science program balances theory with practice, offers an extensive set of traditional and cutting-edge courses, and provides the necessary flexibility to accommodate working professionals with various backgrounds. The program appeals to those with undergraduate degrees in computer science seeking to broaden or deepen their understanding, as well as scientists and engineers who wish to gain deeper insights into the field. The program is also a good option for those with practical computer science experience wishing to formalize their computer science background.

Courses are offered at the Applied Physics Laboratory and online.

PROGRAM COMMITTEE

LANIER WATKINS, PROGRAM CHAIR
Senior Professional Staff
JHU Applied Physics Laboratory

ROBERT S. GROSSMAN, VICE PROGRAM CHAIR EMERITUS
Principal Professional Staff (retired)
JHU Applied Physics Laboratory

ELEANOR BOYLE CHLAN, PROGRAM MANAGER
Senior Professional Staff
JHU Applied Physics Laboratory

ANTHONY JOHNSON, ASSISTANT PROGRAM MANAGER
Senior Professional Staff
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JACKIE AKINPELU
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YAIR AMIR
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Executive Director, Information Security Institute
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Board Director
SAIC

DEBORAH FRINCKE

JOHN A. PIORKOWSKI
Principal Professional Staff
JHU Applied Physics Laboratory

J. MILLER WHISNANT
Principal Professional Staff
JHU Applied Physics Laboratory

**A track or concentration must be chosen for this program.*

REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include the following prerequisites: (1) one year of calculus; (2) a mathematics course beyond calculus (e.g., discrete mathematics, linear algebra, or differential equations); (3) a programming course using Java or C++ (note that actual competency in Java is expected); (4) a course in data structures; and (5) a course in computer organization. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering (all prerequisites beyond calculus are available) or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Applicants may submit a detailed résumé if they would like their academic and professional background to be considered.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students are required to choose a track to follow. The curriculum consists of three foundation courses and five courses from the Computer Science program, which includes selected courses from the Cybersecurity (695.xxx) and Information Systems Engineering (635.xxx) programs as listed throughout the Courses section. At least three courses must be from the same track, at least three must be at the 700-level, and at least one 700-level course must be in the chosen track. Up to two electives may be selected. Courses NOT listed in the Courses section are considered electives for Computer Science and require prior advisor approval. Transfer courses will be considered electives. Transfer courses must meet all general EP requirements for transfer, must be directly applicable to Computer Science, and will be considered on a case-by-case basis. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

Graduate students who are not pursuing a master's degree in Computer Science should consult with their advisor to determine which courses must be successfully completed before 600- or 700-level Computer Science courses may be taken.

CONCENTRATION

COMMUNICATIONS AND NETWORKING

Ten courses must be completed within five years. The curriculum consists of three foundation courses from the program and seven concentration courses as listed in the Courses by Concentration section, of which a maximum of three may come from the Electrical and Computer Engineering (525.xxx) program. Students are strongly encouraged to take courses from both Computer Science and Electrical and Computer Engineering. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

Students lacking an electrical engineering background or equivalent must take 525.202 Signals and Systems as an undergraduate prerequisite before taking Electrical and Computer Engineering communications and networking courses.

Concentrations are noted on the student's transcript.

POST-MASTER'S CERTIFICATE IN COMPUTER SCIENCE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in computer science or a closely related technical discipline, such as electrical and computer engineering or applied and computational mathematics, are eligible to apply for the Post-Master's Certificate in Computer Science.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Five of the six courses must be from the Computer Science program as listed throughout the Courses section, and at least two of these courses must be at the 700-level. Only grades of B– or above can be counted toward the post-master's certificate. Students are allowed to take one elective.

Tracks are not applicable for students pursuing certificates. All course selections, including the elective, are subject to advisor approval.

BIOINFORMATICS JOINT PROGRAM

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

COURSES

PREREQUISITE COURSES

605.101 Introduction to Python
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

Applicants whose prior education does not include the prerequisites listed under Admission Requirements may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. All prerequisite courses beyond calculus are available at Johns Hopkins Engineering. These courses do not count toward the degree or certificate requirements.

FOUNDATION COURSES

Students working toward a master's degree in Computer Science are required to take the following three foundation courses before taking any other courses.

605.601 Foundations of Software Engineering
605.611 Foundations of Computer Architecture
605.621 Foundations of Algorithms

One or more foundation courses can be waived by the student's advisor if a student has received an A or B in equivalent graduate 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.

COURSES BY TRACK

The tracks offered represent related groups of courses that are relevant for students with interests in the selected areas. Students are required to choose a track to follow and to take at least three courses from the selected track, including at least one 700-level course. The tracks are presented as an aid to students in planning their course selections and are only applicable to students seeking a master's degree. They do not appear as official designations on a student's transcript or diploma.

BIOINFORMATICS

605.651 Principles of Bioinformatics
605.652 Biological Databases and Database Tools
605.653 Computational Genomics
605.656 Computational Drug Discovery and Development
605.657 Statistics for Bioinformatics
605.751 Algorithms for Structural Bioinformatics
605.754 Analysis of Gene Expression and High-Content Biological Data
605.755 Systems Biology
605.759 Independent Project in Bioinformatics
605.643 Linked Data and the Semantic Web
605.716 Modeling and Simulation of Complex Systems

CYBERSECURITY

695.601 Foundations of Information Assurance
695.611 Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms
695.612 Operating Systems Security
695.614 Security Engineering
695.615 Cyber Physical System Security
695.621 Public Key Infrastructure and Managing E-Security
695.622 Web Security
695.641 Cryptology
695.642 Intrusion Detection
695.643 Introduction to Ethical Hacking
695.711 Java Security
695.712 Authentication Technologies in Cybersecurity
695.721 Network Security
695.741 Information Assurance Analysis
695.742 Digital Forensics Technologies and Techniques
695.744 Reverse Engineering and Vulnerability Analysis
695.749 Cyber Exercise
695.791 Information Assurance Architectures and Technologies

DATA COMMUNICATIONS AND NETWORKING

605.671 Principles of Data Communications Networks
605.672 Computer Network Architectures and Protocols
605.673 High-Speed Internet Architecture, Technologies, and Applications
605.674 Network Programming
605.675 Protocol Design and Simulation
605.677 Internetworking with TCP/IP I
605.678 Next Generation Mobile Networks with 5G
605.771 Wired and Wireless Local and Metropolitan Area Networks
605.772 Network and Security Management
605.775 Optical Networking Technology
605.776 Fourth-Generation Wireless Communications: WiMAX and LTE
605.777 Internetworking with TCP/IP II
605.778 Voice Over IP
605.779 Network Design and Performance Analysis

525.768 Wireless Networks
600.647 Advanced Topics in Wireless Networks*

DATA SCIENCE AND CLOUD COMPUTING

605.631 Statistical Methods for Computer Science
605.632 Graph Analytics
605.633 Social Media Analytics
605.634 Crowdsourcing and Human Computation
605.635 Cloud Computing
605.649 Introduction to Machine Learning
605.662 Data Visualization
605.724 Applied Game Theory
605.725 Queuing Theory with Applications to Computer Science
605.726 Game Theory
605.731 Cloud Computing Security
605.741 Large-Scale Database Systems
605.744 Information Retrieval
605.746 Advanced Machine Learning
605.788 Big Data Processing Using Hadoop
685.648 Data Science

DATABASE SYSTEMS AND KNOWLEDGE MANAGEMENT

605.641 Principles of Database Systems
605.643 Linked Data and the Semantic Web
605.644 XML Design Paradigms
605.645 Artificial Intelligence
605.646 Natural Language Processing
605.647 Neural Networks
605.649 Introduction to Machine Learning
605.741 Large-Scale Database Systems
605.744 Information Retrieval
605.745 Reasoning Under Uncertainty
605.746 Advanced Machine Learning
605.747 Evolutionary Computation
605.748 Semantic Natural Language Processing
605.624 Logic: Systems, Semantics, and Models
685.648 Data Science
525.643 Real-Time Computer Vision
525.733 Deep Vision

ENTERPRISE AND WEB COMPUTING

605.681 Principles of Enterprise Web Development
605.682 Web Application Development with Java
605.684 Agile Development with Ruby on Rails
605.686 Mobile Application Development for the Android Platform
605.687 Mobile Application Development for the iOS Platform

* *600.xxx courses are offered through the full-time Department of Computer Science.*

605.784 Enterprise Computing with Java
605.785 Web Services with SOAP and REST: Frameworks, Processes, and Applications
605.786 Enterprise System Design and Implementation
605.787 Front End Web App Development
605.788 Big Data Processing Using Hadoop
635.683 E-Business: Models, Architecture, Technologies, and Infrastructure

HUMAN–COMPUTER INTERACTION AND VISUALIZATION

635.661 Principles of Human–Computer Interaction
605.662 Data Visualization
605.667 Computer Graphics
605.767 Applied Computer Graphics
605.634 Crowdsourcing and Human Computation

SOFTWARE ENGINEERING

605.601 Foundations of Software Engineering
605.602 Secure Software Analysis and Design
605.604 Object-Oriented Programming with C++
605.606 Programming with Domain-Specific Languages
605.607 Agile Software Development Methods
605.608 Software Project Management
605.609 DevOps Software Development
605.629 Programming Languages
605.701 Software Systems Engineering
605.702 Service-Oriented Architecture
605.704 Object-Oriented Analysis and Design
605.705 Software Safety
605.707 Software Patterns
605.708 Tools and Techniques of Software Project Management
605.709 Seminar in Software Engineering
695.744 Reverse Engineering and Vulnerability Analysis

SYSTEMS

605.611 Foundations of Computer Architecture
605.612 Operating Systems
605.614 System Development in the UNIX Environment
605.615 Compiler Design with LLVM
605.616 Multiprocessor Architecture and Programming
605.617 Introduction to GPU Programming
605.713 Robotics
605.715 Software Development for Real-Time Embedded Systems
605.716 Modeling and Simulation of Complex Systems

THEORY

605.620 Algorithms for Bioinformatics
605.621 Foundations of Algorithms
605.622 Computational Signal Processing
605.623 Introduction to Enumerative Combinatorics

605.624 Logic: Systems, Semantics, and Models
605.625 Probabilistic Graph Models
605.626 Image Processing
605.627 Computational Photography
605.628 Applied Topology
605.629 Programming Languages
605.721 Design and Analysis of Algorithms
605.724 Applied Game Theory
605.725 Queuing Theory with Applications to Computer Science
605.726 Game Theory
605.727 Computational Geometry
605.728 Quantum Computation
605.729 Formal Methods
625.690 Computational Complexity and Approximation

INDEPENDENT STUDY

605.801 Independent Study in Computer Science I
605.802 Independent Study in Computer Science II

COURSES BY CONCENTRATION

COMMUNICATIONS AND NETWORKING CONCENTRATION

PREREQUISITE

525.202 Signals and Systems

This course does not count toward degree or certificate requirements.

ELECTIVES (SELECT SEVEN; NO MORE THAN THREE COURSES MAY COME FROM ELECTRICAL AND COMPUTER ENGINEERING 525.XXX)

525.608 Next-Generation Telecommunications
525.614 Probability and Stochastic Processes for Engineers
525.616 Communication Systems Engineering
525.618 Antenna Systems
525.620 Electromagnetic Transmission Systems
525.638 Introduction to Wireless Technology
525.640 Satellite Communications Systems
525.641 Computer and Data Communication Networks
525.707 Error Control Coding
525.708 Iterative Methods in Communications Systems
525.722 Wireless and Mobile Cellular Communications
525.735 MIMO Wireless Communications
525.738 Advanced Antenna Systems
525.747 Speech Processing
525.751 Software Radio for Wireless Communications
525.754 Wireless Communication Circuits
525.759 Image Compression, Packet Video, and Video Processing
525.761 Wireless and Wireline Network Integration
525.768 Wireless Networks
525.771 Propagation of Radio Waves in the Atmosphere
525.772 Fiber-Optic Communication Systems
525.776 Information Theory
525.783 Spread-Spectrum Communications
525.789 Advanced Satellite Communications
525.791 Microwave Communications Laboratory
525.793 Advanced Communication Systems
605.671 Principles of Data Communications Networks
605.672 Computer Network Architectures and Protocols
605.673 High-Speed Internet Architecture, Technologies, and Applications
605.674 Network Programming
605.675 Protocol Design and Simulation
605.677 Internetworking with TCP/IP I
605.678 Next Generation Mobile Networks with 5G
605.771 Wired and Wireless Local and Metropolitan Area Networks
605.772 Network and Security Management
605.775 Optical Networking Technology
605.776 Fourth-Generation Wireless Communications: WiMAX and LTE
605.777 Internetworking with TCP/IP II
605.778 Voice Over IP
695.601 Foundations of Information Assurance
695.622 Web Security
695.721 Network Security

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

CYBERSECURITY

- **Master of Science in Cybersecurity**
  Tracks: Analysis; Networks; or Systems*
- **Post-Master's Certificate in Cybersecurity**

The part-time Cybersecurity program balances theory with practice, providing students with the highly technical knowledge and skills needed to protect and defend information systems from attack. Students choose from tracks that explore cyber attacks from within a system, protect information assets, and identify anomalies and unexpected patterns.

Courses are offered at the Applied Physics Laboratory and online.

PROGRAM COMMITTEE

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ANTON DAHBURA
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Board Director
SAIC

DEBORAH FRINCKE

JOHN A. PIORKOWSKI
Principal Professional Staff
JHU Applied Physics Laboratory

J. MILLER WHISNANT
Principal Professional Staff
JHU Applied Physics Laboratory

**A track must be chosen for this program.*

REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include the following prerequisites: (1) one year of calculus; (2) a mathematics course beyond calculus (e.g. discrete mathematics, linear algebra, or differential equations); (3) a programming course using Java or C++ (note that actual competency in Java is expected); (4) a course in data structures; and (5) a course in computer organization. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering (all prerequisites beyond calculus are available) or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Applicants may submit a detailed résumé if they would like their academic and professional background to be considered.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students are required to choose a track to follow. The curriculum consists of three foundation courses and five courses from the Cybersecurity program, which includes selected courses from the Computer Science (605.xxx) program, the Information Security Institute (650.xxx), and Applied Mathematics and Statistics (550.xxx) as listed throughout the Courses section. At least three courses must be from the same track. At least three courses must be at the 700-level, and at least one 700-level course must be in the chosen track. Up to two electives may be selected. Courses NOT listed in the Courses section are considered electives for Cybersecurity, and require prior advisor approval. Transfer courses will be considered electives. Transfer courses must meet all general EP requirements for transfer, must be directly applicable to Cybersecurity, and will be considered on a case-by-case basis. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

Graduate students who are not pursuing a master's degree in Cybersecurity should consult with their advisor to determine which courses must be successfully completed before 600- or 700-level courses may be taken.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post-Master's Certificate in Cybersecurity.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Five of the six courses must be from the Cybersecurity program as listed throughout the Courses section, and at least two of these courses must be at the 700-level. Only grades of B- or above can be counted toward the post master's certificate. Students are allowed to take one elective.

Tracks are not applicable for students pursuing certificates. All course selections, including the elective, are subject to advisor approval.

COURSES

PREREQUISITE COURSES

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

Applicants whose prior education does not include the prerequisites listed under Admission Requirements may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. All prerequisite courses beyond calculus are available at Johns Hopkins Engineering. These courses do not count toward the degree or certificate requirements.

FOUNDATION COURSES

Students working toward a master's degree in Cybersecurity are required to take the following three foundation courses.

605.621 Foundations of Algorithms
695.601 Foundations of Information Assurance
695.641 Cryptology

605.621 Foundations of Algorithms and 695.601 Foundations of Information Assurance should be taken before any other courses. 695.641 Cryptology should be taken after the other two foundation courses and before any other courses in the Analysis track.

One or more foundation courses can be waived by the student's advisor if a student has received an A or B in equivalent graduate 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.

COURSES BY TRACK

The tracks offered represent related groups of courses that are relevant for students with interests in the selected areas. Students are required to choose a track to follow and to take at least three courses from the selected track, including at least one 700-level course. The tracks are presented as an aid to students in planning their course selections and are only applicable to students seeking a master's degree. They do not appear as official designations on a student's transcript or diploma.

The three tracks each have additional requirements. Applicants should have had a course in networking prior to taking courses in the Networks track, a course in operating systems prior to taking courses in the Systems track, and a course in both before taking courses in the Analysis track. If necessary, 605.612 Operating Systems and 605.671 Principles of Data Communications Networks can be taken and applied toward the master's degree in Cybersecurity.

ANALYSIS

695.641 Cryptology
695.642 Intrusion Detection
695.643 Introduction to Ethical Hacking
695.741 Information Assurance Analysis
695.742 Digital Forensics Technologies and Techniques
695.744 Reverse Engineering and Vulnerability Analysis
695.749 Cyber Exercise
605.728 Quantum Computation
650.656 Computer Forensics*

NETWORKS

695.621 Public Key Infrastructure and Managing E-Security
695.622 Web Security
695.721 Network Security
695.791 Information Assurance Architectures and Technologies
605.671 Principles of Data Communications Networks
605.672 Computer Network Architectures and Protocols
605.674 Network Programming
605.675 Protocol Design and Simulation
605.771 Wired and Wireless Local and Metropolitan Area Networks
601.642 Modern Cryptography†

SYSTEMS

695.601 Foundations of Information Assurance
695.611 Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms
695.612 Operating Systems Security
695.614 Security Engineering
695.615 Cyber Physical System Security
695.711 Java Security
695.712 Authentication Technologies in Cybersecurity
605.601 Foundations of Software Engineering
605.612 Operating Systems
605.621 Foundations of Algorithms
605.704 Object-Oriented Analysis and Design
605.715 Software Development for Real-Time Embedded Systems
605.716 Modeling and Simulation of Complex Systems
605.729 Formal Methods
601.643 Security and Privacy in Computing†
650.671 Cryptography & Coding*

INDEPENDENT STUDY

695.801 Independent Study in Cybersecurity I
695.802 Independent Study in Cybersecurity II

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

** 650.xxx courses are offered through the Information Security Institute.*

† 601.xxx courses are offered through the full-time Department of Computer Science.

DATA SCIENCE

- **Master of Science in Data Science**
- **Post-Master's Certificate in Data Science**

The part-time Data Science program balances theory and applications so that you can advance your career long term.

The rigorous curriculum focuses on the fundamentals of computer science, statistics, and applied mathematics, while incorporating real-world examples. By learning from practicing engineers and data scientists, graduates are prepared to succeed in specialized jobs involving everything from the data pipeline and storage to statistical analysis and eliciting the story the data tells.

Courses are offered online as well as in-person at the Applied Physics Laboratory. The Master of Science degree or Post-Master's Certificate may be completed fully online, fully in person, or via a blend of the two.

PROGRAM COMMITTEE

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REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include the following prerequisites: (1) multivariate calculus; (2) discrete mathematics; (3) courses in Java or C++ (note that actual competency in Java is expected and that Python can be accepted on a case-by-case basis); and (4) a course in data structures. Linear Algebra or Differential Equations will be accepted in lieu of Discrete Mathematics. A grade of B– or better must have been earned in each of the prerequisite courses. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering (all prerequisites beyond calculus are available) or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Applicants may submit a detailed résumé if they would like their academic and professional background to be considered.

Undergraduate courses are offered to satisfy computer science and mathematics beyond calculus requirements.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of seven required courses, one Applied and Computational Mathematics (625.xxx) elective, and two 700-level electives. Only one C-range grade (C+, C, or C–) can count toward the master's degree. Any grade for a course lower than a C will not be counted toward the degree. All course selections are subject to advisor approval.

Courses applied toward undergraduate or graduate degrees at other institutions (non-JHU) are not eligible for transfer or double counting to a Data Science master's degree or post-master's certificate. Up to two graduate courses taken outside of JHU after an undergraduate degree was conferred and not applied toward a graduate degree may be considered toward the Data Science master's degree subject to advisor approval.

Graduate students who are not pursuing a master's degree in Data Science should consult with their advisor to determine which courses must be successfully completed before 600- or 700-level Data Science courses may be taken.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in Data Science or a very closely related field, such as Applied Statistics, are eligible to apply for the Post-Master's Certificate in Data Science. Coursework should have included coursework comparable to at least three of the four required courses in both the Computer Science area and the Applied and Computational Mathematics area, respectively.

Exceptions to these requirements, based on experience, can be made by the program chairs.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least three courses must be from the Applied and Computational Mathematics program (625.xxx), and at least three courses must be from the Computer Science program (605.xxx). At least four of the courses must be 700-level with at least two from Computer Science and at least two from Applied and Computational Mathematics. Only grades of B– or above can be counted toward the post-master's certificate. 625.603 Statistical Methods and Data Analysis may not be applied to the post-master's certificate. One graduate course taken outside of JHU and not applied toward a graduate or other degree may be considered toward the Data Science Post-Master's Certificate, subject to advisor approval. All course selections are subject to advisor approval.

COURSES

PREREQUISITE COURSES

605.101 Introduction to Python
605.201 Introduction to Programming Using Java
605.202 Data Structures
605.203 Discrete Mathematics
625.201 General Applied Mathematics
625.250 Multivariable and Complex Analysis
625.251 Introduction to Ordinary and Partial Differential Equations

Applicants whose prior education does not include the prerequisites listed under Admission Requirements may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. All prerequisite courses beyond calculus are available at Johns Hopkins Engineering. These courses do not count toward the degree or certificate requirements.

FOUNDATION COURSES

685.621 Algorithms for Data Science
625.603 Statistical Methods and Data Analysis

These required foundation courses must be taken or waived before all other courses in their respective programs.

REQUIRED COURSES

685.648 Data Science
605.662 Data Visualization
625.661 Statistical Models and Regression

AND ONE OF THE FOLLOWING:

605.641 Principles of Database Systems
605.649 Introduction to Machine Learning

AND ONE OF THE FOLLOWING:

625.615 Introduction to Optimization*
625.664 Computational Statistics

And ONE 625.xxx course selected from Electives or Additional Selections.

Students who have been waived from foundation or required courses may replace the courses with the same number of other graduate courses. 605.xxx courses must be replaced with 605.xxx courses and 625.xxx courses must be replaced with 625.xxx courses. Students who waive 605.641 must replace it with 605.741 Large-Scale Database Systems. Students who waive 685.621 must replace it with 605.641 Principles of Database Systems OR 605.649 Introduction to Machine Learning. Students who take outside electives from other programs must meet the specific course prerequisites listed.

ELECTIVES

SELECT ONE

605.741 Large-Scale Database Systems
605.746 Advanced Machine Learning
605.748 Semantic Natural Language Processing
605.788 Big Data Processing Using Hadoop

SELECT ONE

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
625.741 Game Theory
625.743 Stochastic Optimization and Control
625.744 Modeling, Simulation, and Monte Carlo

* 625.616 Optimization in Finance may be substituted for 625.615.

ADDITIONAL SELECTIONS

Students waiving required courses may choose from the list of 700-level electives or from the courses below. The replacement course should be from the same field (605.xxx or 625.xxx) as the waived course.

605.625 Probabilistic Graphical Models
605.628 Applied Topology
605.632 Graph Analytics
605.633 Social Media Analytics
605.635 Cloud Computing
605.647 Neural Networks
605.649 Introduction to Machine Learning
605.724 Applied Game Theory
605.725 Queuing Theory with Applications to Computer Science
605.726 Game Theory
625.601 Real Analysis
625.609 Matrix Theory
625.611 Computational Methods
625.620 Mathematical Methods for Signal Processing
625.623 Introduction to Operations Research: Probabilistic Models
625.633 Monte Carlo Methods
625.636 Graph Theory
625.638 Neural Networks
625.641 Mathematics of Finance: Investment Science
625.642 Mathematics of Risk, Options, and Financial Derivatives
625.662 Design and Analysis of Experiments
625.663 Multivariate Statistics and Stochastic Analysis
625.665 Bayesian Statistics
625.680 Cryptography
625.687 Applied Topology
625.690 Computational Complexity and Approximation
625.692 Probabilistic Graphical Models
625.695 Time Series Analysis and Dynamic Modeling
625.717 Advanced Differential Equations: Partial Differential Equations
625.718 Advanced Differential Equations: Nonlinear Differential Equations and Dynamical Systems
625.728 Theory of Probability

INDEPENDENT STUDY

685.795 Capstone Project in Data Science
685.801 Independent Study in Data Science I
685.802 Independent Study in Data Science II

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

ELECTRICAL AND COMPUTER ENGINEERING

- **Master of Science in Electrical and Computer Engineering**
  Concentrations: Communications and Networking or Photonics*
  Focus Areas: Communications and Networking; Computer Engineering; Electronics and the Solid State; Optics and Photonics; RF and Microwave Engineering; Signal Processing; or Systems and Control*
- **Post-Master's Certificate in Electrical and Computer Engineering**
- **Graduate Certificate in Electrical and Computer Engineering**

The part-time Electrical and Computer Engineering program's strength lies in its faculty, who are drawn from the Applied Physics Laboratory, from government and local industry, and from the full-time Department of Electrical & Computer Engineering. Their active involvement in applied research and development helps to foster students' understanding of the theory and practice of the discipline. Students study the fundamentals of electrical and computer engineering, as well as more specific aspects of current technologies based on a variety of technical groupings of courses.

Courses are offered at the Applied Physics Laboratory and online.

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**A concentration or focus area is not required for this program.*

REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. Applicants are expected to hold a degree in electrical and/or computer engineering issued by a program accredited by the Engineering Accreditation Commission (EAC) of ABET, http://www.abet.org, in order to be admitted to the Master of Science in Electrical and Computer Engineering program. Those 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. Applicants' prior education should include the following prerequisites: (1) mathematics through vector calculus and differential equations, (2) calculus-based physics, (3) linear and non-linear circuits, (4) electromagnetics, and (5) signals and systems. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering (all prerequisites beyond calculus are available) or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Transcripts from all college studies must be submitted. When reviewing an application, the candidate's academic and professional background will be considered.

Exceptions to these requirements can be made by the program chair or admissions committee.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. At least seven of the ten courses must be from the Electrical and Computer Engineering program (525.xxx) or the Department of Electrical and Computer Engineering (520.xxx) in the full-time program, and at least four of the ten required courses must be at the 700-level or above. Approved transfer courses count as 600-level courses.

At most, three of the ten courses required for the MS degree may be selected from outside the program, subject to advisor approval. Students who take an elective outside of the program typically select from approved offerings from the Applied and Computational Mathematics (625.xxx), Applied Physics (615.xxx), and Computer Science (605.xxx) programs.

Limited opportunity is available for replacement of coursework by appropriate project work (525.801 and 525.802) or through a graduate thesis (525.803 and 525.804). Note that 615.641 Mathematical Methods for Physics and Engineering, 615.642 Electromagnetics, 615.780 Optical Detectors and Applications, and 625.743 Stochastic Optimization and Control are counted as Electrical and Computer Engineering courses rather than electives. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

CONCENTRATIONS

COMMUNICATIONS AND NETWORKING

Ten courses must be completed within five years. Of the minimum of seven Electrical and Computer Engineering courses, at least five must be Communications and Networking courses. Of the maximum of three electives, at least two must be Computer Science Communications and Networking courses. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

Concentrations are noted on the student's transcript.

PHOTONICS

Ten courses must be completed within five years. The curriculum consists of four photonics core courses and three additional photonics courses, with the three remaining courses selected to fulfill the MS degree requirements. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

Concentrations are noted on the student's transcript.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post-Master's Certificate in Electrical and Computer Engineering.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least four of the six courses must be from the Electrical and Computer Engineering (525.xxx) program or the Department of Electrical and Computer Engineering (520.xxx) in the full-time program. Students are allowed to take two electives. Only grades of B– or above can count toward the post-master's certificate. All course selections are subject to advisor approval.

GRADUATE CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate-level courses but not necessarily interested in pursuing a full master's degree are eligible for the Graduate Certificate in Electrical and Computer Engineering. Applicants are required to meet the same requirements for admission as the master's degree.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare their intention prior to completing the certificate.

CERTIFICATE REQUIREMENTS

Five courses must be completed within three years. At least four of the five courses must be from the Electrical and Computer Engineering (525.xxx) program or the Department of Electrical and Computer Engineering (520.xxx) in the full-time program. Students are allowed to take one elective. Only grades of B– or above can count toward the graduate certificate. All course selections are subject to advisor approval.

COURSES

PREREQUISITE COURSES

525.201 Circuits, Devices, and Fields
525.202 Signals and Systems

Applicants whose prior education does not include the prerequisites listed under Admission Requirements may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. All prerequisite courses beyond calculus are available at Johns Hopkins Engineering. These courses do not count toward the degree or certificate requirements.

FOCUS AREAS

The focus areas offered represent technology groupings that are relevant for students with interests in the selected areas. Students are not required to choose a focus area to follow. They only serve as an aid to students in planning their course schedules. They do not appear as official designations on a student's transcript or diploma.

COMMUNICATIONS AND NETWORKING

525.608 Next-Generation Telecommunications
525.614 Probability and Stochastic Processes for Engineers
525.616 Communication Systems Engineering
525.618 Antenna Systems
525.620 Electromagnetic Transmission Systems
525.638 Introduction to Wireless Technology
525.640 Satellite Communications Systems
525.641 Computer and Data Communication Networks
525.654 Communications Circuits Laboratory
525.707 Error Control Coding
525.708 Iterative Methods in Communications Systems
525.722 Wireless and Mobile Cellular Communications
525.735 MIMO Wireless Communications
525.738 Advanced Antenna Systems
525.747 Speech Processing
525.751 Software Radio for Wireless Communications
525.752 Digital Receiver Synchronization Techniques
525.754 Wireless Communication Circuits
525.759 Image Compression, Packet Video, and Video Processing
525.761 Wireless and Wireline Network Integration
525.768 Wireless Networks
525.771 Propagation of Radio Waves in the Atmosphere
525.772 Fiber-Optic Communication Systems
525.776 Information Theory
525.783 Spread-Spectrum Communications
525.789 Advanced Satellite Communications
525.791 Microwave Communications Laboratory
525.793 Advanced Communication Systems

COMPUTER ENGINEERING

525.610 Microprocessors for Robotic Systems
525.612 Computer Architecture
525.615 Embedded Microprocessor Systems
525.634 High-Speed Digital Design and Signal Integrity
525.641 Computer and Data Communication Networks
525.642 FPGA Design Using VHDL
525.712 Advanced Computer Architecture
525.742 System-on-a-Chip FPGA Design Laboratory
525.743 Embedded Systems Development Laboratory
525.778 Design for Reliability, Testability, and Quality Assurance
525.786 Human–Robotics Interaction

ELECTRONICS AND THE SOLID STATE

525.606 Electronic Materials
525.607 Introduction to Electronic Packaging
525.621 Introduction to Electronics and the Solid State
525.623 Principles of Microwave Circuits
525.624 Analog Electronic Circuit Design
525.651 Introduction to Electric Power Systems
525.654 Communications Circuits Laboratory
525.658 Digital VLSI System Design
525.659 Mixed-Mode VLSI Circuit Design
525.725 Power Electronics
525.732 Advanced Analog Electronic Circuit Design
525.754 Wireless Communication Circuits

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

OPTICS AND PHOTONICS

525.613 Fourier Techniques in Optics
525.625 Laser Fundamentals
525.636 Optics and Photonics Laboratory
525.691 Fundamentals of Photonics
525.753 Laser Systems and Applications
525.756 Optical Propagation, Sensing, and Backgrounds
525.772 Fiber-Optic Communication Systems
525.796 Introduction to High-Speed Optoelectronics
525.797 Advanced Fiber Optic Laboratory

RF AND MICROWAVE ENGINEERING

525.605 Intermediate Electromagnetics
525.618 Antenna Systems
525.620 Electromagnetic Transmission Systems
525.623 Principles of Microwave Circuits
525.648 Introduction to Radar Systems
525.654 Communications Circuits Laboratory
525.684 Microwave Systems and Receiver Design
525.738 Advanced Antenna Systems
525.754 Wireless Communication Circuits
525.771 Propagation of Radio Waves in the Atmosphere
525.774 RF and Microwave Circuits I
525.775 RF and Microwave Circuits II
525.779 RF Integrated Circuits
525.787 Microwave Monolithic Integrated Circuit (MMIC) Design
525.788 Power Microwave Monolithic Integrated Circuit (MMIC) Design
525.790 RF Power Amplifier Design Techniques
525.791 Microwave Communications Laboratory
615.642 Electromagnetics

SIGNAL PROCESSING

525.614 Probability and Stochastic Processes for Engineers
525.619 Introduction to Digital Image and Video Processing
525.627 Digital Signal Processing
525.630 Digital Signal Processing Lab
525.631 Adaptive Signal Processing
525.638 Introduction to Wireless Technology
525.643 Real-Time Computer Vision
525.646 DSP Hardware Lab
525.648 Introduction to Radar Systems
525.670 Machine Learning for Signal Processing
525.718 Multirate Signal Processing
525.721 Advanced Digital Signal Processing
525.724 Introduction to Pattern Recognition
525.728 Detection and Estimation Theory
525.733 Deep Vision
525.735 MIMO Wireless Communications
525.744 Passive Emitter Geo-Location
525.745 Applied Kalman Filtering
525.746 Image Engineering
525.747 Speech Processing
525.748 Synthetic Aperture Radar
525.751 Software Radio for Wireless Communications
525.759 Image Compression, Packet Video, and Video Processing
525.762 Signal Processing with Wavelets
525.780 Multidimensional Digital Signal Processing
625.603 Statistical Methods and Data Analysis
625.609 Matrix Theory
625.620 Mathematical Methods for Signal Processing
625.710 Fourier Analysis with Applications to Signal Processing and Differential Equations

SYSTEMS AND CONTROL

520.633 Introduction to Robust Control
520.636 Feedback Control in Biological Signaling Pathways
525.609 Continuous Control Systems
525.614 Probability and Stochastic Processes for Engineers
525.645 Modern Navigation Systems
525.661 UAV Systems and Control
525.666 Linear System Theory
525.744 Passive Emitter Geo-Location
525.745 Applied Kalman Filtering
525.770 Intelligent Algorithms
525.777 Control System Design Methods
535.645 Digital Control and Systems Applications
535.726 Robot Control
605.713 Robotics
605.716 Modeling and Simulation of Complex Systems
625.615 Introduction to Optimization
625.695 Time Series Analysis and Dynamic Modeling
625.714 Introductory Stochastic Differential Equations with Applications
625.743 Stochastic Optimization and Control
695.615 Cyber Physical System Security

SPECIAL PROJECT/THESIS COURSES

525.801 Special Project I
525.802 Special Project II
525.803 Electrical and Computer Engineering Thesis
525.804 Electrical and Computer Engineering Thesis

COURSES BY CONCENTRATION

COMMUNICATIONS AND NETWORKING

SELECT FIVE

525.608 Next-Generation Telecommunications
525.614 Probability and Stochastic Processes for Engineers
525.616 Communication Systems Engineering
525.618 Antenna Systems
525.620 Electromagnetic Transmission Systems
525.638 Introduction to Wireless Technology
525.640 Satellite Communications Systems
525.641 Computer and Data Communication Networks
525.654 Communications Circuits Laboratory
525.707 Error Control Coding
525.708 Iterative Methods in Communications Systems
525.722 Wireless and Mobile Cellular Communications
525.735 MIMO Wireless Communications
525.738 Advanced Antenna Systems
525.747 Speech Processing
525.751 Software Radio for Wireless Communications
525.754 Wireless Communication Circuits
525.759 Image Compression, Packet Video, and Video Processing
525.761 Wireless and Wireline Network Integration
525.768 Wireless Networks
525.771 Propagation of Radio Waves in the Atmosphere
525.772 Fiber-Optic Communication Systems
525.776 Information Theory
525.783 Spread-Spectrum Communications
525.789 Advanced Satellite Communications
525.791 Microwave Communications Laboratory
525.793 Advanced Communication Systems

SELECT TWO

605.671 Principles of Data Communications Networks
605.672 Computer Network Architectures and Protocols
605.673 High-Speed Internet Architecture, Technologies, and Applications
605.674 Network Programming
605.675 Protocol Design and Simulation
605.677 Internetworking with TCP/IP I
605.678 Next Generation Mobile Networks with 5G
605.771 Wired and Wireless Local and Metropolitan Area Networks
605.772 Network and Security Management
605.775 Optical Networking Technology
605.776 Fourth-Generation Wireless Communications: WiMAX and LTE
605.777 Internetworking with TCP/IP II
605.778 Voice Over IP
695.622 Web Security
695.641 Cryptology
695.721 Network Security

PHOTONICS

CORE COURSES (ONLY ONE 615.XXX COURSE IS REQUIRED)

525.613 Fourier Techniques in Optics
525.625 Laser Fundamentals
525.691 Fundamentals of Photonics
615.641 Mathematical Methods for Physics and Engineering
615.654 Quantum Mechanics
615.671 Principles of Optics

ELECTIVES FOR THE CONCENTRATION (SELECT THREE)

525.636 Optics and Photonics Laboratory
525.753 Laser Systems and Applications
525.756 Optical Propagation, Sensing, and Backgrounds
525.772 Fiber-Optic Communication Systems
525.796 Introduction to High-Speed Optoelectronics
525.797 Advanced Fiber Optic Laboratory
585.734 Biophotonics
615.751 Modern Optics
615.758 Modern Topics in Applied Optics
615.778 Computer Optical Design
615.780 Optical Detectors and Applications
615.781 Quantum Information Processing
615.782 Optics and MATLAB

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

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

ENGINEERING MANAGEMENT

- **Master of Engineering Management**
  Concentrations: Applied Biomedical Engineering; Applied and Computational Mathematics; Applied Physics; Communications, Controls, and Signal Processing; Computer Engineering; Computer Science; Cybersecurity; Information Systems Engineering; Materials Science and Engineering; Mechanical Engineering; Optics and Photonics; RF and Microwave Engineering; or Structural Engineering*

The part-time Engineering Management program prepares ethically grounded, technically competent professional leaders with the technical, managerial, and leadership skills to produce innovative solutions to technical organizations' challenges. While management courses serve as the core of the program at Johns Hopkins Engineering for Professionals, students work within technical concentrations that span various engineering disciplines. The concentrations provide for graduate-level work giving students a unique opportunity to mix their chosen technical concentration with engineering management perspectives. The curriculum provides a unique opportunity to build both technical and leaderships skills in order to contribute to a multi-disciplinary engineering management team. Instructors are experienced technical leaders and executives who discuss real-world challenges in formats that are convenient for professionals working at the nation's top engineering firms and R&D organizations.

Courses are offered in person at the Applied Physics Laboratory as well as in the distant learning environment. Several concentrations can be completed online.

ENGINEERING MANAGEMENT AND TECHNICAL MANAGEMENT PROGRAMS COMMITTEE

TIM COLLINS
Programs Chair, Engineering Management and Technical Management
JHU Whiting School of Engineering

RICK BLANK
Programs Coordinator, Engineering Management and Technical Management
JHU Whiting School of Engineering

ANN KEDIA
Principal Professional Staff
JHU Applied Physics Laboratory

DAN REGAN
Director, Federal Healthcare Business Development
CACI International, Inc.

PAMELA SHEFF
Director, Master of Science in Engineering Management Program
JHU Whiting School of Engineering

STAS TARCHALSKI
Director, IBM (retired)

A concentration must be chosen for this program.

REQUIREMENTS

MASTER'S

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to a graduate program outlined in the Admission Requirements section on page 3 and must be accepted into both the Engineering Management program and their respective engineering concentration program. The applicant's prior education must include a degree in a science or an engineering field. In addition to this requirement, a minimum of two years of relevant full-time work experience in the field is required, and a detailed work résumé and transcripts from all college studies must be submitted. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of five core courses and five courses from the concentration. At least three of the ten courses must be at the 700-level. Only one C-range grade (C+, C, or C–) can count toward the master's degree. Concentrations are noted on the student's transcript. All course selections are subject to advisor approval.

COURSES

CORE COURSES

SELECT FIVE

Course substitutions can be made at the discretion of the program chair.

595.660 Planning and Managing Projects
595.665 Communications in Technical Organizations
595.666 Financial and Contract Management
595.731 Business Law for Technical Professionals
595.762 Management of Technical Organizations
595.781 Executive Technical Leadership
595.793 Applied Innovation for Technical Professionals

COURSES BY CONCENTRATION

APPLIED BIOMEDICAL ENGINEERING

Select five courses from the Applied Biomedical Engineering program (ep.jhu.edu/abe) 585.xxx. The advisor from the concentration will have the flexibility to work with each student to determine the appropriate mix of technical courses. All ABE courses require previous coursework in molecular biology, signal processing, and math through ordinary differential equations.

Note: Students must pay close attention to prerequisites when selecting courses.

APPLIED AND COMPUTATIONAL MATHEMATICS

Select five graduate-level courses from the Applied and Computational Mathematics program (ep.jhu.edu/acm) 625.xxx. At least one course must be at the 700-level. The advisor from the concentration will have the flexibility to work with the student to determine the appropriate mix of technical courses.

Note: Students must pay close attention to prerequisites when selecting courses.

One course (with significant math content) outside of Applied and Computational Mathematics may be taken with concentration advisor approval.

APPLIED PHYSICS

SELECT FIVE (AT LEAST FOUR MUST BE 615.XXX COURSES)

Students must complete five courses approved by their concentration advisor. At least four courses must be from Applied Physics. The following courses are recommended for this concentration, but the concentration advisor can approve courses that do not appear on this list.

525.606 Electronic Materials
525.607 Introduction to Electronic Packaging
615.644 Fundamentals of Space Systems and Subsystems I
615.645 Fundamentals of Space Systems and Subsystems II
615.647 Fundamentals of Sensors
615.648 Alternate Energy Technology
615.665 Modern Physics
615.671 Principles of Optics
615.680 Materials Science
615.731 Photovoltaic and Solar Thermal Energy Conversion
615.747 Sensors and Sensor Systems
615.761 Introduction to Oceanography
615.765 Chaos and Its Applications
615.775 Physics of Climate
615.780 Optical Detectors and Applications

ELECTRICAL AND COMPUTER ENGINEERING–COMMUNICATIONS, CONTROLS, AND SIGNAL PROCESSING

CORE COURSES

525.609 Continuous Control Systems
525.614 Probability and Stochastic Processes for Engineers
525.616 Communication Systems Engineering
525.627 Digital Signal Processing

Plus one *additional Electrical and Computer Engineering (525.xxx) course with concentration advisor approval (one course outside of the program may be taken provided it has significant technical content).*

ELECTRICAL AND COMPUTER ENGINEERING–COMPUTER ENGINEERING

CORE COURSES

525.612 Computer Architecture
525.615 Embedded Microprocessor Systems
525.642 FPGA Design Using VHDL
525.743 Embedded Systems Development Laboratory

Plus one *additional Electrical and Computer Engineering (525.xxx) course with concentration advisor approval (one course outside of the program may be taken provided it has significant technical content).*

COMPUTER SCIENCE

Applicants for admission to Computer Science need to have completed a year of calculus and a suitable math beyond calculus (such as discrete mathematics, calculus 3, linear algebra, or differential equations). Java or C++, data structures, and computer organization are also required.

CORE COURSES

605.601 Foundations of Software Engineering
605.611 Foundations of Computer Architecture
605.621 Foundations of Algorithms

SELECT ONE

605.635 Cloud Computing
605.641 Principles of Database Systems
605.645 Artificial Intelligence
605.651 Principles of Bioinformatics
605.671 Principles of Data Communications Networks
605.681 Principles of Enterprise Web Development
695.601 Foundations of Information Assurance

Plus one *additional Computer Science course with concentration advisor approval.*

CYBERSECURITY

Applicants for admission to Cybersecurity need to have completed a year of calculus and a suitable math beyond calculus (such as discrete mathematics, calculus 3, linear algebra, or differential equations). Java or C++, data structures, and computer organization are also required.

CORE COURSES

605.621 Foundations of Algorithms
695.601 Foundations of Information Assurance
695.641 Cryptology

Plus two *additional Cybersecurity courses. Both courses require concentration advisor approval.*

This concentration can be completed fully online.

INFORMATION SYSTEMS ENGINEERING

CORE COURSES

605.601 Foundations of Software Engineering
635.601 Foundations of Information Systems Engineering
695.601 Foundations of Information Assurance

SELECT ONE

635.611 Principles of Network Engineering
635.621 Principles of Decision Support Systems
635.631 Foundations of Data Analytics
635.661 Principles of Human–Computer Interaction
635.671 Data Recovery and Continuing Operations
635.673 Critical Infrastructure
635.676 Cybersecurity in Information Systems
635.683 E-Business: Models, Architecture, Technologies, and Infrastructure

Plus one *additional Information Systems Engineering course with concentration advisor approval.*

MATERIALS SCIENCE AND ENGINEERING

Select five courses from the Materials Science and Engineering program (ep.jhu.edu/mse) 515.xxx. The advisor from the concentration will have the flexibility to work with each student to determine the appropriate mix of technical courses.

MECHANICAL ENGINEERING

All students are required to take 535.641 Mathematical Methods for Mechanical Engineers. This course is typically taken as the first technical course in the program. There are three different sections of this course, and the appropriate one that most closely matches the interests of the student should be chosen. In addition, select four other technical courses from the Mechanical Engineering program (ep.jhu.edu/me) 535.xxx with concentration advisor approval.

ELECTRICAL AND COMPUTER ENGINEERING–OPTICS AND PHOTONICS

CORE COURSES

525.605 Intermediate Electromagnetics
525.613 Fourier Techniques in Optics
525.625 Laser Fundamentals
525.691 Fundamentals of Photonics

Plus one *additional Electrical and Computer Engineering (525.xxx) course with concentration advisor approval (one course outside of the program may be taken provided it has significant technical content).*

ELECTRICAL AND COMPUTER ENGINEERING–RF AND MICROWAVE ENGINEERING

CORE COURSES

525.605 Intermediate Electromagnetics
525.618 Antenna Systems
525.623 Principles of Microwave Circuits
525.684 Microwave Systems and Receiver Design

Plus one *additional Electrical and Computer Engineering (525.xxx) course with concentration advisor approval (courses outside of the program may be taken provided they have significant technical content).*

STRUCTURAL ENGINEERING

Students must complete five courses in Structural Engineering (ep.jhu.edu/ce) 565.xxx approved by their concentration advisor. The following courses are recommended for this concentration, but the concentration advisor can approve courses that do not appear in this list:

565.604 Structural Mechanics
565.616 Applied Finite Element Methods
565.620 Advanced Steel Design
565.622 Advanced Reinforced Concrete Design
565.623 Bridge Design and Evaluation
565.626 Design of Wood Structures
565.628 Preservation Engineering I: Theory and Practice
565.630 Prestressed Concrete Design
565.631 Preservation Engineering II: Theory and Practice
565.633 Investigation, Diagnosis, and Rehabilitation
565.636 Lateral Forces: Analysis and Design of Building Structures
565.637 Preservation Engineering in the Urban Context
565.658 Natural Disaster Risk Modeling
565.682 Design of Ocean Structures
565.731 Structural Dynamics
565.732 Earthquake Engineering
565.734 Wind Engineering
565.764 Retaining Structures and Slope Stability

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

ENVIRONMENTAL ENGINEERING, SCIENCE, AND MANAGEMENT PROGRAMS

The part-time programs in Environmental Engineering, Science, and Management address an array of modern environmental and health issues while capitalizing on environmental protection and remediation solutions made possible by technology. Students enhance their knowledge in these areas through a quantitative program built around the common theme of engineering, science, and health in support of environmental decision-making and management. The strength of the programs lies in a faculty of working professionals and from the nationally renowned full-time Department of Environmental Health and Engineering hosted jointly in the Whiting School of Engineering and the Bloomberg School of Public Health at Johns Hopkins University. All of the environmental degree and certificate programs are offered exclusively online.

PROGRAM COMMITTEE

HEDY ALAVI, PROGRAM CHAIR
Assistant Dean for International Programs, JHU Whiting School of Engineering
Associate Teaching Professor, Department of Environmental Health and Engineering

EDWARD BOUWER
Abel Wolman Professor of Environmental Engineering, Department of Environmental Health and Engineering

KIRSTEN KOEHLER
Associate Professor, Department of Environmental Health and Engineering

MEGAN LATSHAW
Assistant Scientist and Co-director, MHS and ScM Master's Programs, Department of Environmental Health and Engineering

SCOT MILLER
Assistant Professor, Department of Environmental Health and Engineering

CARSTEN PRASSE
Assistant Professor, Department of Environmental Health and Engineering

HARIHAR RAJARAM
Professor, Department of Environmental Health and Engineering

GURUMURTHY RAMACHANDRAN
Professor, Department of Environmental Health and Engineering

This committee ensures that instruction in the part-time program is of the highest quality and is continually enhanced in a manner consistent with parallel developments in the full-time program.

FACULTY

The program features highly qualified instructors who are distinguished and experienced professionals. Each holds the highest academic degree in their field of expertise and has demonstrated a strong commitment to excellence in teaching. Many of the outstanding full-time faculty from the renowned full-time Department of Environmental Health and Engineering serve as instructors. The program also includes directors, senior scientists, engineers, researchers, and attorneys affiliated with the US Environmental Protection Agency, American Academy of Environmental Engineers and Scientists, Maryland Department of the Environment, Nuclear Regulatory Agency, US Department of Energy, US Department of Defense, and many leading environmental consulting companies.

Please see the Faculty section on page 209 for the list of current faculty members and their affiliations.

ENVIRONMENTAL ENGINEERING

- **Master of Environmental Engineering** *(online only)*
  Focus Area: Environmental and Occupational Health
- **Post-Master's Certificate in Environmental Engineering** *(online only)*
- **Graduate Certificate in Environmental Engineering** *(online only)*
- **Certificate in Environmental and Occupational Health** *(online only)*

REQUIREMENTS

MASTER OF ENVIRONMENTAL ENGINEERING

The degree and certificates offered under this program emphasize the design of environmental processes, infrastructures, remediation technologies, and treatment processes.

MASTER'S

ADMISSION REQUIREMENTS

Applicants (degree seeking and special students) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. In order to be admitted into the Master of Environmental Engineering program, applicants need to hold a degree issued by a program accredited by the Engineering Accreditation Commission (EAC) of ABET, http://www.abet.org. The applicant's prior education must also include successful completion of mathematics courses that include a calculus sequence and differential equations. Successful completion of a course in fluid mechanics or hydraulics is strongly recommended. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in their undergraduate studies. Transcripts from all college studies must be submitted. When reviewing an application, the candidate's academic and professional background will be considered.

Applicants with an undergraduate degree in natural sciences may be admitted as provisional students to complete additional undergraduate coursework in engineering fundamentals and design prior to full admission to the program.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of five courses from the Environmental Engineering program and five electives. Electives may be selected from any of the three environmental areas of study: Environmental Engineering, Environmental Engineering and Science, or Environmental Planning and Management, subject to prerequisite restrictions. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

The Principles of Environmental Engineering (575.604) course is required of all degree students in the Environmental Engineering program who do not possess an undergraduate degree in Environmental Engineering, Science, and Management or a related discipline.

Electives might also include up to 9 "term" credits from the list of approved Bloomberg School of Public Health (BSPH) courses provided at the end of this section, that is equivalent of two EP semester courses. Please note that 1 EP semester credit equals 1.5 BSPH term credits.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post-Master's Certificate in Environmental Engineering.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least three of the six courses must be taken within the Environmental Engineering program. Only grades of B– or above can count toward the post-master's certificate.

All course selections are subject to advisor approval.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

GRADUATE CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate-level courses but not necessarily interested in pursuing a full master's degree might be eligible for the Graduate Certificate in Environmental Engineering. Applicants are required to meet the same requirements for admission as the master's degree.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. Students must declare their intention prior to completing the certificate.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Only grades of B– or above can count toward the graduate certificate. All course selections are subject to advisor approval.

Any deviation from these requirements, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

ENVIRONMENTAL AND OCCUPATIONAL HEALTH

The fundamental connection between adverse effects of environmental agents on human health and the environmental engineering interventions designed to address them has led to interest in offering a program of coursework that would address both components. In response, these options link environmental health-related courses to the three current areas of study within the EP Environmental Engineering, Science, and Management programs. This builds upon and further strengthens the teaching, research, and training activities in which faculty in Environmental Engineering and Environmental Health have cooperatively participated over the past several decades. As the need for the integration of these two fields to address emerging complex environmental hazards continues to grow, this approach enables students to better face these new challenges. These options are established in collaboration with the Johns Hopkins Department of Environmental Health and Engineering (EHE) that is hosted jointly in the Bloomberg School of Public Health (BSPH) and the Whiting School of Engineering.

ENVIRONMENTAL AND OCCUPATIONAL HEALTH FOCUS AREA

To accommodate students interested in the human health aspects of the environment, a focus area in "Environmental and Occupational Health" is offered within all three EP environmental master's degree programs—the Master of Environmental Engineering, the Master of Science in Environmental Engineering and Science, and the Master of Science in Environmental Planning and Management. Students must take at least 14 BSPH "term" credits from the EHE courses listed below to substitute for an equivalent of 9 EP semester credits (three semester courses) of their elective courses required for the designated 30-credit EP master's degree program. Please note that 1 EP semester credit equals 1.5 BSPH term credits.

BLOOMBERG SCHOOL OF PUBLIC HEALTH CERTIFICATE

Students may earn the Certificate in Environmental and Occupational Health by completing at least a total of 18 BSPH "term" credits—including the 14 BSPH term credits applied to the EP degree—from the list of BSPH courses below. This is to substitute an equivalent of 9 EP semester credits (three semester courses) of their elective courses required for the designated 30-credit EP master's degree program. Three or more of the BSPH courses must come from those that are indicated by an asterisk (*) and must be taken for a letter grade. Other courses may be taken pass/fail, and students must earn a minimum grade point average of 2.75 in all certificate coursework.

The student must apply to WSE-EP first and gain admission to the master's degree program. The student will then apply to BSPH to seek admission to the certificate program. Please visit the BSPH website for application details (jhsph.edu).

BLOOMBERG SCHOOL OF PUBLIC HEALTH COURSES

180.601 Environmental Health (5 BSPH Term Credits)*
180.607 Climate Change and Public Health (3 BSPH Term Credits)
182.622 Ventilation Controls (4 BSPH Term Credits)
182.623 Occupational Safety and Health Management (3 BSPH Term Credits)
182.625 Principles of Occupational and Environmental Hygiene (4 BSPH Term Credits)*
182.637 Noise and Other Physical Agents in the Environment (4 BSPH Term Credits)
187.610 Public Health Toxicology (4 BSPH Term Credits)*
188.680 Fundamentals of Occupational Health (3 BSPH Term Credits)*
188.682 A Built Environment for a Healthy and Sustainable Future (3 BSPH Term Credits)

COURSES

FOR ENVIRONMENTAL ENGINEERING

SELECT A MINIMUM OF FIVE COURSES

575.604 Principles of Environmental Engineering*
575.605 Principles of Water and Wastewater Treatment
575.606 Water Supply and Wastewater Collection
575.607 Radioactive Waste Management
575.620 Solid Waste Engineering and Management
575.623 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
575.722 Sensor Applications for Environmental Monitoring and Exposure Assessment
575.741 Membrane Filtration Fundamentals and Applications in Water and Wastewater Treatment
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
575.761 Measurement Theory and Practices in the Environmental Arena
575.762 Resilience of Complex Systems
575.801 Independent Project in Environmental Engineering, Science, and Management

Required only for students who do not possess an undergraduate degree in Environmental Engineering, Science, Management, or a related discipline.

Plus select a maximum of five courses from those listed on pages 66 and 69, including BSPH focus/certificate courses.

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

ENVIRONMENTAL ENGINEERING AND SCIENCE

- **Master of Science in Environmental Engineering and Science** *(online only)*
  Focus Area: Environmental and Occupational Health
- **Post-Master's Certificate in Environmental Engineering and Science** *(online only)*
- **Graduate Certificate in Environmental Engineering and Science** *(online only)*
- **Certificate in Environmental and Occupational Health** *(online only)*

REQUIREMENTS

MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING AND SCIENCE

The degree and certificates offered under this program emphasizes the fundamental concepts of physics, chemistry, biology, and geology as applied in the context of environmental issues, with less emphasis on design and management.

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include (1) an undergraduate degree from a regionally accredited four-year college or university, (2) successful completion of one year of college-level calculus, and (3) successful completion of a college-level course in differential equations. Successful completion of college-level courses in physics, chemistry, biology, geology, and statistics is strongly recommended. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in their undergraduate studies. Transcripts from all college studies must be submitted. When reviewing an application, the candidate's academic and professional background will be considered.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of five courses from the Environmental Engineering and Science program and five electives. Electives may be selected from any of the three environmental areas of study: Environmental Engineering, Environmental Engineering and Science, or Environmental Planning and Management, subject to prerequisite restrictions. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

The Principles of Environmental Engineering (575.604) course is required of all degree students in the Environmental Engineering program who do not possess an undergraduate degree in Environmental Engineering, Science, and Management or a related discipline.

Electives might also include up to 9 "term" credits from the list of approved Bloomberg School of Public Health (BSPH) courses provided at the end of this section, that is equivalent of two EP semester courses. Please note that 1 EP semester credit equals 1.5 BSPH term credits.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post-Master's Certificate in Environmental Engineering and Science.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least three of the six courses must be taken within the Environmental Engineering and Science program. Only grades of B– or above can count toward the post-master's certificate. All course selections are subject to advisor approval.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

GRADUATE CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate-level courses, but not necessarily interested in pursuing a full master's degree are eligible for the Graduate Certificate in Environmental Engineering and Science. Applicants are required to meet the same requirements for admission as the master's degree.

Applicants must have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Significant relevant work experience or a graduate degree in a relevant technical discipline may be considered in lieu of meeting the GPA requirement.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare their intention prior to completing the certificate.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Only grades of B– or above can count toward the graduate certificate. All course selections are subject to advisor approval.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

ENVIRONMENTAL AND OCCUPATIONAL HEALTH

The fundamental connection between adverse effects of environmental agents on human health and the environmental engineering interventions designed to address them has led to interest in offering a program of coursework that would address both components. In response, these options link environmental health-related courses to the three current areas of study within the EP Environmental Engineering, Science, and Management programs. This builds upon and further strengthens the teaching, research, and training activities in which faculty in Environmental Engineering and Environmental Health have cooperatively participated over the past several decades. As the need for the integration of these two fields to address emerging complex environmental hazards continues to grow, this approach enables students to better face these new challenges. These options are established in collaboration with the Johns Hopkins Department of Environmental Health and Engineering (EHE) that is hosted jointly in the Bloomberg School of Public Health (BSPH) and the Whiting School of Engineering.

ENVIRONMENTAL AND OCCUPATIONAL HEALTH FOCUS AREA

To accommodate students interested in the human health aspects of the environment, a focus area in "Environmental and Occupational Health" is offered within all three EP environmental master's degree programs—the Master of Environmental Engineering, the Master of Science in Environmental Engineering and Science, and the Master of Science in Environmental Planning and Management. Students must take at least 14 BSPH "term" credits from the EHE courses listed below to substitute for an equivalent of 9 EP semester credits (three semester courses) of their elective courses required for the designated 30-credit EP master's degree program. Please note that 1 EP semester credit equals 1.5 BSPH term credits.

BLOOMBERG SCHOOL OF PUBLIC HEALTH CERTIFICATE

Students may earn the Certificate in Environmental and Occupational Health by completing at least a total of 18 BSPH term credits—including the 14 BSPH term credits—from the list of BSPH courses below. This is to substitute an equivalent of 9 EP semester credits (three semester courses) of their elective courses required for the designated 30-credit EP master's degree program. Three or more of the BSPH courses must come from those that are indicated by an asterisk (*) and must be taken for a letter grade. Other courses may be taken pass/fail, and students must earn a minimum grade point average of 2.75 in all certificate coursework.

The student must apply to WSE-EP first and gain admission to the master's degree program. The student will then apply to BSPH to seek admission to the certificate program. Please visit the BSPH website for application details (jhsph.edu).

BLOOMBERG SCHOOL OF PUBLIC HEALTH COURSES

180.601 Environmental Health (5 BSPH Term Credits)*
180.607 Climate Change and Public Health (3 BSPH Term Credits)
182.622 Ventilation Controls (4 BSPH Term Credits)
182.623 Occupational Safety and Health Management (3 BSPH Term Credits)

182.625 Principles of Occupational and Environmental Hygiene (4 BSPH Term Credits)*
182.637 Noise and Other Physical Agents in the Environment (4 BSPH Term Credits)
187.610 Public Health Toxicology (4 BSPH Term Credits)*
188.680 Fundamentals of Occupational Health (3 BSPH Term Credits)*
188.682 A Built Environment for a Healthy and Sustainable Future (3 BSPH Term Credits)

COURSES

REQUIRED COURSE

575.604 Principles of Environmental Engineering*

** Required only for students who do not possess an undergraduate degree in Environmental Engineering, Science, Management, or a related discipline*

COURSES FOR ENVIRONMENTAL ENGINEERING AND SCIENCE

SELECT A MINIMUM OF FIVE COURSES

575.601 Fluid Mechanics
575.615 Ecology
575.619 Principles of Toxicology, Risk Assessment, and Management
575.626 Hydrogeology
575.629 Modeling Contaminant Migration through Multimedia Systems
575.643 Chemistry of Aqueous Systems
575.645 Environmental Microbiology
575.704 Applied Statistical Analyses and Design of Experiments for Environmental Applications
575.708 Open-Channel Hydraulics
575.713 Field Methods in Habitat Analysis and Wetland Delineation
575.716 Principles of Estuarine Environment: The Chesapeake Bay Science and Management
575.717 Hydrology
575.720 Air Resources Management and Modeling
575.727 Environmental Monitoring and Sampling
575.728 Sediment Transport and River Mechanics
575.730 Geomorphic and Ecologic Foundations of Stream Restoration
575.743 Atmospheric Chemistry
575.744 Environmental Chemistry
575.763 Nanotechnology and the Environment: Applications and Implications
575.801 Independent Project in Environmental Engineering, Science, and Management

Plus select a maximum of five courses from those listed on pages 63 and 69, including BSPH focus/certificate courses.

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

ENVIRONMENTAL PLANNING AND MANAGEMENT

- **Master of Science in Environmental Planning and Management** *(online only)*
  Focus Area: Environmental and Occupational Health
- **Post-Master's Certificate in Environmental Planning and Management** *(online only)*
- **Graduate Certificate in Environmental Planning and Management** *(online only)*
- **Certificate in Environmental and Occupational Health** *(online only)*

REQUIREMENTS

MASTER OF SCIENCE IN ENVIRONMENTAL PLANNING AND MANAGEMENT

The degree and certificates offered under this program emphasizes the relationship between environmental engineering, science and public policy analysis. Students will also focus on the role of economic factors in the planning and management of environmental recourses using proven decision-making tools.

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include (1) an undergraduate degree from a regionally accredited four-year college or university and (2) successful completion of one year of college-level calculus. Successful completion of college-level courses in physics, chemistry, biology, geology, and statistics is strongly recommended. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in their undergraduate studies. Transcripts from all college studies must be submitted. When reviewing an application, the candidate's academic and professional background will be considered.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of five courses from the Environmental Planning and Management program and five electives. Electives may be selected from any of the three environmental areas of study: Environmental Engineering, Environmental Engineering and Science, or Environmental Planning and Management, subject to prerequisite restrictions. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

The Principles of Environmental Engineering (575.604) course is required of all degree students in the Environmental Engineering program who do not possess an undergraduate degree in Environmental Engineering, Science, and Management or a related discipline.

Electives might also include up to 9 "term" credits from the list of approved Bloomberg School of Public Health (BSPH) courses provided at the end of this section, that is equivalent of two EP semester courses. Please note that 1 EP semester credit equals 1.5 BSPH term credits.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post-Master's Certificate in Environmental Planning and Management.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least three of the six courses must be taken within the Environmental Planning and Management program. Only grades of B– or above can count toward the post-master's certificate.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

GRADUATE CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate-level courses, but not necessarily interested in pursuing a full master's degree might be eligible for the Graduate Certificate in Environmental Planning and Management. Applicants are required to meet the same requirements for admission as the master's degree.

Applicants must have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Significant relevant work experience or a graduate degree in a relevant technical discipline may be considered in lieu of meeting the GPA requirement.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare their intention prior to completing the certificate.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Only grades of B– or above can count toward the graduate certificate. All course selections are subject to advisor approval.

Any deviation from this program, including transfer of courses and any other requisites specified in the student's admission letter, will not be approved by the program chair.

ENVIRONMENTAL AND OCCUPATIONAL HEALTH

The fundamental connection between adverse effects of environmental agents on human health and the environmental engineering interventions designed to address them has led to interest in offering a program of coursework that would address both components. In response, these options link environmental health-related courses to the three current areas of study within the EP Environmental Engineering, Science, and Management programs. This builds upon and further strengthens the teaching, research, and training activities in which faculty in Environmental Engineering and Environmental Health have cooperatively participated over the past several decades. As the need for the integration of these two fields to address emerging complex environmental hazards continues to grow, this approach enables students to better face these new challenges. These options are established in collaboration with the Johns Hopkins Department of Environmental Health and Engineering (EHE) that is hosted jointly in the Bloomberg School of Public Health (BSPH) and the Whiting School of Engineering.

ENVIRONMENTAL AND OCCUPATIONAL HEALTH FOCUS AREA

To accommodate students interested in the human health aspects of the environment, a focus area in "Environmental and Occupational Health" is offered within all three EP environmental master's degree programs—the Master of Environmental Engineering, the Master of Science in Environmental Engineering and Science, and the Master of Science in Environmental Planning and Management. Students must take at least 14 BSPH "term" credits from the EHE courses listed below to substitute for an equivalent of 9 EP semester credits (three semester courses) of their elective courses required for the designated 30-credit EP master's degree program. Please note that 1 EP semester credit equals 1.5 BSPH term credits.

BLOOMBERG SCHOOL OF PUBLIC HEALTH CERTIFICATE

Students may earn the Certificate in Environmental and Occupational Health by completing at least a total of 18 BSPH "term" credits—including the 14 BSPH term credits applied to the EP degree—from the list of BSPH courses below. This is to substitute an equivalent of 9 EP semester credits (three semester courses) of their elective courses required for the designated 30-credit EP master's degree program. Three or more of the BSPH courses must come from those that are indicated by an asterisk (*) and must be taken for a letter grade. Other courses may be taken pass/fail, and students must earn a minimum grade point average of 2.75 in all certificate coursework.

The student must apply to WSE-EP first and gain admission to the master's degree program. The student will then apply to BSPH to seek admission to the certificate program. Please visit the BSPH website for application details (jhsph.edu).

BLOOMBERG SCHOOL OF PUBLIC HEALTH COURSES

180.601 Environmental Health (5 BSPH Term Credits)*
180.607 Climate Change and Public Health (3 BSPH Term Credits)
182.622 Ventilation Controls (4 BSPH Term Credits)
182.623 Occupational Safety and Health Management (3 BSPH Term Credits)
182.625 Principles of Occupational and Environmental Hygiene (4 BSPH Term Credits)*

182.637 Noise and Other Physical Agents in the Environment (4 BSPH Term Credits)
187.610 Public Health Toxicology (4 BSPH Term Credits)*
188.680 Fundamentals of Occupational Health (3 BSPH Term Credits)*
188.682 A Built Environment for a Healthy and Sustainable Future (3 BSPH Term Credits)

COURSES

REQUIRED COURSE

575.604 Principles of Environmental Engineering*

* *Required only for students who do not possess an undergraduate degree in Environmental Engineering, Science, Management, or a related discipline*

COURSES FOR ENVIRONMENTAL PLANNING AND MANAGEMENT

SELECT A MINIMUM OF FIVE COURSES

575.608 Optimization Methods for Public Decision Making
575.611 Economic Foundations for Public Decision Making
575.628 Business Law for Engineers
575.635 Environmental Law for Engineers and Scientists
575.637 Environmental Impact Assessment
575.640 Geographic Information Systems (GIS) and Remote Sensing for Environmental Applications
575.658 Natural Disaster Risk Modeling
575.707 Environmental Compliance Management
575.710 Financing Environmental Projects
575.711 Climate Change and Global Environmental Sustainability
575.714 Water Resources Management
575.723 Sustainable Development and Next-Generation Buildings
575.731 Water Resources Planning
575.733 Energy Planning and the Environment
575.734 Smart Growth Strategies for Sustainable Urban Development and Revitalization
575.735 Energy Policy and Planning Modeling
575.736 Designing for Sustainability: Applying a Decision Framework
575.737 Environmental Security with Applied Decision Analysis Tools
575.747 Environmental Project Management
575.750 Environmental Policy Needs in Developing Countries
575.752 Environmental Justice and Ethics Incorporated into Environmental Decision Making
575.753 Communication of Environmental Information and Stakeholder Engagement
575.759 Environmental Policy Analysis
575.801 Independent Project in Environmental Engineering, Science, and Management

Plus select a maximum of five courses from those listed on pages 63 and 69, including BSPH focus/certificate courses.

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

FINANCIAL MATHEMATICS

- Master of Science in Financial Mathematics
- Graduate Certificate in Financial Risk Management
- Graduate Certificate in Quantitative Portfolio Management
- Graduate Certificate in Securitization

The Financial Mathematics program aims to equip graduates with the engineering-driven approaches widely used to construct and deploy the financial transactions and processes that, in their context, function as the international financial system and the capital markets. These are the mechanisms enabling the creation/employment of wealth and for the worldwide distribution of well-being within the constraints and intent of global financial policy.

This program is only offered online.

PROGRAM COMMITTEE

DAVID AUDLEY, PROGRAM CHAIR
Senior Lecturer
JHU Whiting School of Engineering

REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include (1) an undergraduate or graduate degree in a quantitative discipline (e.g., mathematics, engineering, or the sciences) from a regionally accredited college or university and (2) at least two years of experience in finance or a related field. Applicants must show competency (generally, through their undergraduate transcripts) in (1) calculus, through multivariable calculus; (2) linear algebra; (3) differential equations; (4) probability and statistics; and (5) computer programming, which must be demonstrated through coursework, MOOC course completion with verification, or work experience. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Transcripts from all college studies must be submitted. When reviewing an application, the candidate's academic and professional background will be considered.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum nominally consists of nine core courses and one elective. Only one C-range grade (C+, C, or C–) can count toward the master's degree.

GRADUATE CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate-level courses, but not necessarily interested in pursuing a full master's degree are eligible for a Graduate Certificate in Financial Risk Management, Quantitative Portfolio Management, or Securitization. Applicants are required to meet the same requirements for admission as the master's degree.

CERTIFICATE REQUIREMENTS

Five courses must be completed within three years. Only grades of B– or above may be counted toward the certificate.

COURSES

CORE COURSES

555.642 Investment Science OR
625.641 Mathematics of Finance: Investment Science
555.644 Introduction to Financial Derivatives
555.645 Interest Rate and Credit Derivatives
555.646 Financial Risk Measurement and Management
625.603 Statistical Methods and Data Analysis
625.616 Optimization in Finance
625.633 Monte Carlo Methods
625.695 Time Series Analysis and Dynamic Modeling
625.714 Introductory Stochastic Differential Equations with Applications

SELECT ONE

555.647 Quantitative Portfolio Theory & Performance Analysis
555.648 Financial Engineering and Structured Products

GRADUATE CERTIFICATE COURSES

FINANCIAL RISK MANAGEMENT

555.642 Investment Science OR
625.641 Mathematics of Finance: Investment Science
555.644 Introduction to Financial Derivatives
555.646 Financial Risk Measurement and Management
625.603 Statistical Methods and Data Analysis
625.633 Monte Carlo Methods

QUANTITATIVE PORTFOLIO MANAGEMENT

555.642 Investment Science OR
625.641 Mathematics of Finance: Investment Science
555.644 Introduction to Financial Derivatives
555.647 Quantitative Portfolio Theory & Performance Analysis
625.603 Statistical Methods and Data Analysis
625.616 Optimization in Finance

SECURITIZATION

555.642 Investment Science OR
625.641 Mathematics of Finance: Investment Science
555.644 Introduction to Financial Derivatives
555.648 Financial Engineering and Structured Products
625.603 Statistical Methods and Data Analysis
625.633 Monte Carlo Methods

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

HEALTHCARE SYSTEMS ENGINEERING

- **Master of Science in Healthcare Systems Engineering**

The Healthcare Systems Engineering program at Johns Hopkins University provides engineers and healthcare professionals with the in-depth knowledge and skills necessary to apply systems engineering principles and best practices to address today's healthcare challenges and create healthcare of the future. Students will be well prepared to re-engineer healthcare delivery on a broad scale by using a systems approach. This approach will lead to solutions that seamlessly integrate technology into the cultural and workflow dynamics prevalent in healthcare, while holistically addressing interoperability, security/privacy, safety, cost, performance (i.e., outcomes, etc.), and other key requirements.

Instructors are practicing systems engineers or healthcare professionals who incorporate real-world problem-solving activities and case studies into discussion topics.

Courses are offered online. Selected electives from the Bloomberg School of Public Health are offered in-person for those students that prefer a classroom setting.

PROGRAM COMMITTEE

ALAN RAVITZ, PROGRAM CHAIR
Principal Professional Staff
JHU Applied Physics Laboratory

CONRAD GRANT
Principal Professional Staff
JHU Applied Physics Laboratory

ROBERT STOLL
Senior Professional Staff
JHU Applied Physics Laboratory

ADAM SAPIRSTEIN
Director, Division of Adult Critical Care Medicine
Associate Professor of Anesthesiology and Critical Care Medicine

MICHAEL GRANT
Assistant Professor, Johns Hopkins University School of Medicine, Department of Anesthesiology and Critical Care Medicine

REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

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.

In addition, applicants for the Master of Science in Healthcare Systems Engineering must have a prior educational experience that includes an undergraduate major in engineering or the sciences. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Transcripts from all college studies must be submitted. When reviewing an application, the candidate's academic and professional background will be considered. Applicants will typically have at least two years' experience in engineering or the healthcare field. A detailed professional experience résumé must be submitted.

DEGREE REQUIREMENTS

In order to earn a Master of Science in Healthcare Systems Engineering, the student must complete 30 credits, approved by an advisor, within five years. The curriculum consists of six required core courses (18 credits) and 12 credits of electives. Subject to advisor approval, an elective may be substituted for a required course if the student has previously completed an equivalent graduate-level course. With the permission of an advisor, the student may be able to select a relevant elective not listed below. Only one grade of C can count toward the master's degree. All course selections are subject to advisor approval.

COURSES

CORE COURSES (18 CREDITS)

655.662 Introduction to Healthcare Systems Engineering
655.667 Management of Healthcare Systems Projects
655.767 Healthcare System Conceptual Design
655.768 Healthcare System Design and Integration
655.769 Healthcare System Test and Evaluation
655.800 Healthcare Systems Engineering Capstone Project

ELECTIVES (12 CREDITS)

HEALTHCARE SYSTEMS ENGINEERING

585.613 Medical Sensors and Devices
655.771 Healthcare Systems
655.772 Healthcare Networks and Databases
655.773 Designing for Patient Safety

SYSTEMS ENGINEERING

645.650 Foundations of Human Systems Engineering
645.651 Integrating Humans and Technology
645.742 Management of Complex Systems
645.754 Social and Organizational Factors in Human Systems Engineering
645.755 Methods in Human-System Performance Measurement and Analysis
645.761 Systems Architecting
645.771 System of Systems Engineering

BLOOMBERG SCHOOL OF PUBLIC HEALTH

140.611 Statistical Methods in Public Health I (3 BSPH credits/2 EP credits)*
140.612 Statistical Methods in Public Health II (3 BSPH credits/2 EP credits)*
140.651 Methods in Biostatistics I (3 BSPH credits/2 EP credits)
140.652 Methods in Biostatistics II (3 BSPH credits/2 EP credits)
309.600 Evaluating Quality Improvement and Patient Safety Programs (3 BSPH credits/2 EP credits)*
309.730 Patient Safety and Medical Errors (3 BSPH credits/2 EP credits)*
309.732 Human Factors in Patient Safety (3 BSPH credits/2 EP credits)
311.615 Quality of Medical Care (3 BSPH credits/2 EP credits)*
340.721 Epidemiologic Inference in Public Health I (3 BSPH credits/2 EP credits)*
340.722 Epidemiologic Inference in Public Health II (3 BSPH credits/2 EP credits)*

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

** Bloomberg (BSPH) courses with an asterisk refer to online courses; Bloomberg courses without an asterisk refer to in-person courses, which are offered for selected electives should a student prefer a classroom setting.*

INFORMATION SYSTEMS ENGINEERING

- **Master of Science in Information Systems Engineering**
  Tracks: Cybersecurity; Data Engineering; Enterprise and Web Computing; Human–Computer Interaction; Information Management; Network Engineering; Software Engineering; or Systems Engineering*
- **Post-Master's Certificate in Information Systems Engineering**
- **Graduate Certificate in Information Systems Engineering**

The part-time Information Systems Engineering program balances theory with practice by offering traditional and cutting-edge courses that accommodate working professionals with various backgrounds. The program appeals to engineers, scientists, and analysts by providing them with the opportunity to design large-scale information systems, create business analytics, conduct complex systems analyses, and create sophisticated distributed and secure systems.

Courses are offered at the Applied Physics Laboratory and online.

PROGRAM COMMITTEE

JOHN A. PIORKOWSKI, PROGRAM CHAIR
Principal Professional Staff
JHU Applied Physics Laboratory

ELEANOR BOYLE CHLAN, PROGRAM MANAGER
Senior Professional Staff
JHU Applied Physics Laboratory

ANTHONY JOHNSON, ASSISTANT PROGRAM MANAGER
Senior Professional Staff
JHU Applied Physics Laboratory

JACKIE AKINPELU
Principal Professional Staff
JHU Applied Physics Laboratory

YAIR AMIR
Professor and Chair, Department of Computer Science
JHU Whiting School of Engineering

MATT BISHOP
Professor, Department of Computer Science
University of California, Davis

JOEL COFFMAN
Associate Professor
United States Air Force Academy

ANTON DAHBURA
Executive Director, Information Security Institute
Johns Hopkins University

DEBORAH DUNIE
Board Director
SAIC

DEBORAH FRINCKE

J. MILLER WHISNANT
Principal Professional Staff
JHU Applied Physics Laboratory

**A track must be chosen for this program.*

REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants (degree seeking and special student) must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include the following prerequisites: one year of college math (including one semester of calculus or discrete mathematics) and a course in a programming language such as Java or C++. Actual competency in Java is expected. A course in data structures will also be required for students seeking to take selected courses from Computer Science and Cybersecurity. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed with Johns Hopkins Engineering (all prerequisites beyond calculus are available) or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Applicants may submit a detailed résumé if they would like their academic and professional background to be considered.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students are required to choose a track to follow. The curriculum consists of three foundation courses and five courses from the Information Systems Engineering (635.xxx) program, which includes selected courses from the Computer Science (605.xxx), Cybersecurity (695.xxx), Systems Engineering (645.xxx), and Technical Management (595.xxx) programs as listed throughout the Courses section. At least three courses must be from the same track, at least three courses must be at the 700-level, and at least one 700-level course must be in the chosen track. Up to two electives may be selected from other programs. Courses NOT listed in the Courses section are considered electives for Information Systems Engineering and require prior advisor approval. Transfer courses will be considered electives. Transfer courses must meet all general EP requirements for transfer, must be directly applicable to Information Systems Engineering, and will be considered on a case-by-case basis. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

Graduate students who are not pursuing a master's degree in Information Systems Engineering should consult with their advisor to determine which courses must be successfully completed before 600- or 700-level courses may be taken.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post-Master's Certificate in Information Systems Engineering.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Five of the six courses must be from the Information Systems Engineering program, as listed throughout the Courses section, which includes selected courses from the Computer Science (605.xxx), Cybersecurity (695.xxx), Systems Engineering (645.xxx), and Technical Management (595.xxx) programs. At least two of these courses must be at the 700-level. Only grades of B– or above can be counted toward the post-master's certificate. Students are allowed to take one elective.

Tracks are not applicable for students pursuing certificates. All course selections, including the elective, are subject to advisor approval.

GRADUATE CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate-level courses, but not necessarily interested in pursuing a full master's degree are eligible for the Graduate Certificate in Information Systems Engineering. Applicants are required to meet the same requirements for admission as the master's degree.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare their intention prior to completing the certificate.

CERTIFICATE REQUIREMENTS

Five courses must be completed within three years. Four of the five courses must be from the Information Systems Engineering program, as listed throughout the Courses section, which include 635.xxx courses plus selected courses from the Computer Science (605.xxx), Cybersecurity (695.xxx), Systems Engineering (645.xxx), and Technical Management (595.xxx) programs. Students are allowed to take one elective. Tracks are not applicable for students pursuing certificates. All course selections, including the elective, are subject to advisor approval.

COURSES

PREREQUISITES

605.101 Introduction to Python
605.201 Introduction to Programming Using Java
605.202 Data Structures
605.203 Discrete Mathematics

Applicants whose prior education does not include the prerequisites listed under Admission Requirements may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. All prerequisite courses beyond calculus are available at Johns Hopkins Engineering. These courses do not count toward the degree or certificate requirements.

FOUNDATION COURSES

Students working toward a master's degree in Information Systems Engineering are required to take the following three foundation courses before taking any other courses.

605.601 Foundations of Software Engineering
635.601 Foundations of Information Systems Engineering
695.601 Foundations of Information Assurance

One or more foundation courses can be waived by the student's advisor if a student has received an A or B in equivalent graduate 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.

COURSES BY TRACK

The tracks offered represent related groups of courses that are relevant for students with interests in the selected areas. Students are required to choose a track to follow and to take at least three courses from the selected track, including at least one 700-level course. The tracks are presented as an aid to students in planning their course selections and are only applicable to students seeking a master's degree. They do not appear as official designations on a student's transcript or diploma.

CYBERSECURITY*

635.671 Data Recovery and Continuing Operations
635.672 Privacy Engineering
635.673 Critical Infrastructure
635.676 Cybersecurity in Information Systems
635.775 Cyber Operations, Risk, and Compliance
635.776 Building Information Governance
695.601 Foundations of Information Assurance
695.611 Embedded Computer Systems—Vulnerabilities, Intrusions, and Protection Mechanisms
695.614 Security Engineering
695.622 Web Security
695.712 Authentication Technologies in Cybersecurity
695.721 Network Security
695.744 Reverse Engineering and Vulnerability Analysis

DATA ENGINEERING*

635.631 Foundations of Data Analytics
605.635 Cloud Computing
605.662 Data Visualization
605.741 Large-Scale Database Systems
605.744 Information Retrieval
605.788 Big Data Processing Using Hadoop

ENTERPRISE AND WEB COMPUTING*

635.682 Website Development
635.683 E-Business: Models, Architecture, Technologies, and Infrastructure
605.681 Principles of Enterprise Web Development
605.684 Agile Development with Ruby on Rails
605.784 Enterprise Computing with Java
605.785 Web Services with SOAP and REST: Frameworks, Processes, and Applications
605.786 Enterprise System Design and Implementation
605.788 Big Data Processing Using Hadoop

HUMAN–COMPUTER INTERACTION

635.661 Principles of Human–Computer Interaction
605.662 Data Visualization
645.650 Foundations of Human Systems Engineering
645.651 Integrating Humans and Technology

INFORMATION MANAGEMENT*

635.621 Principles of Decision Support Systems
605.641 Principles of Database Systems
605.643 Linked Data and the Semantic Web
605.644 XML Design Paradigms
605.741 Large-Scale Database Systems
605.744 Information Retrieval

NETWORK ENGINEERING

635.611 Principles of Network Engineering
635.711 Advanced Topics in Network Engineering
605.772 Network and Security Management

For students with appropriate backgrounds, the following courses may be taken toward the network engineering track. Advisor approval and permission of the instructor is required.

605.673 High-Speed Internet Architecture, Technologies, and Applications
605.677 Internetworking with TCP/IP I
605.678 Next Generation Mobile Networks with 5G
605.771 Wired and Wireless Local and Metropolitan Area Networks

** This track requires Data Structures.*

605.776 Fourth-Generation Wireless Communications: WiMAX and LTE
605.777 Internetworking with TCP/IP II
605.778 Voice Over IP

SOFTWARE ENGINEERING

605.601 Foundations of Software Engineering
605.602 Secure Software Analysis and Design
605.604 Object-Oriented Programming with C++
605.607 Agile Software Development Methods
605.608 Software Project Management
605.609 DevOps Software Development
605.701 Software Systems Engineering
605.704 Object-Oriented Analysis and Design
605.705 Software Safety
605.708 Tools and Techniques of Software Project Management

SYSTEMS ENGINEERING

635.601 Foundations of Information Systems Engineering
635.792 Management of Innovation
645.650 Foundations of Human Systems Engineering
645.662 Introduction to Systems Engineering
645.667 Management of Systems Projects
645.742 Management of Complex Systems
645.753 Enterprise Systems Engineering
645.754 Social and Organizational Factors in Human Systems Engineering
645.757 Foundations of Modeling and Simulation in Systems Engineering
645.761 Systems Architecting
645.767 System Conceptual Design
595.660 Planning and Managing Projects

INDEPENDENT STUDY AND SPECIAL TOPICS

635.795 Information Systems Engineering Capstone Project
635.801 Independent Study in Information Systems Engineering I
635.802 Independent Study in Information Systems Engineering II

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

MATERIALS SCIENCE AND ENGINEERING

- **Master of Materials Science and Engineering**
  Concentration: Nanotechnology
  Focus Areas: Biotechnology or Nanomaterials*

The part-time Materials Science and Engineering program allows students to take courses that address current and emerging areas critical to the development and use of materials in the areas of biomaterials, electrochemistry, electronic materials, mechanics of materials, nanomaterials and nanotechnology, and materials processing. Students in this program gain an advanced understanding of foundational concepts and are exposed to the latest research that is driving materials-related advances.

Courses are offered at the Applied Physics Laboratory, the Homewood campus, and online.

PROGRAM COMMITTEE

JAMES SPICER, PROGRAM CHAIR
Principal Professional Staff
JHU Applied Physics Laboratory
Professor, Materials Science & Engineering
JHU Whiting School of Engineering

DAWNIELLE FARRAR-GAINES
Senior Professional Staff
JHU Applied Physics Laboratory

JENNIFER SAMPLE
Senior Professional Staff
JHU Applied Physics Laboratory

JOHN SLOTWINSKI
Senior Professional Staff
JHU Applied Physics Laboratory

**A focus area or concentration is not required for this program.*

REQUIREMENTS

MASTER'S DEGREE

ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include a mathematics sequence through linear algebra and/or differential equations as well as courses in general physics and chemistry. This program is best suited to applicants who have received undergraduate degrees in engineering or science. Applicants whose prior education does not include the prerequisites listed above may still be admitted under provisional status, followed by full admission once they have completed the missing prerequisites. Missing prerequisites may be completed at the Johns Hopkins University or at another regionally accredited institution. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Transcripts from all college studies must be submitted. Professional accomplishments may be included in the application by including a résumé along with letters of reference from the applicant's workplace, but this information is optional. When reviewing an application, the applicant's academic and professional background (if submitted) will be considered.

DEGREE REQUIREMENTS

A total of ten courses must be completed within five years. The curriculum consists of two core courses and eight electives in materials science and engineering or related fields (400-level or higher with at least five being at the 600- or 700-level). Courses offered through the Department of Materials Science and Engineering in the full-time program (510.xxx) may count as electives. Students interested in taking the Materials Science and Engineering project courses (515.730/731) or independent study (515.800/801) must get prior approval from the program chair. Up to two courses can be from Engineering Management and/or Technical Management. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

CONCENTRATION

NANOTECHNOLOGY

A total of ten courses must be completed within five years. The curriculum consists of four core courses and six electives in materials science and engineering or related fields (400-level or higher with at least three being at the 600- or 700-level). Courses offered through the Department of Materials Science and Engineering in the full-time program (510.xxx) may count as electives. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

Concentrations are noted on the student's transcript.

COURSES

CORE COURSES

515.601 Structure and Properties of Materials
515.602 Thermodynamics and Kinetics of Materials

COURSES BY CONCENTRATION

NANOTECHNOLOGY

CORE COURSES

515.601 Structure and Properties of Materials
515.602 Thermodynamics and Kinetics of Materials
515.616 Introduction to Nanotechnology
515.617 Nanomaterials

COURSES BY FOCUS AREA

The focus areas offered represent related groups of courses that are relevant for students with interests in the selected areas. The focus areas are presented as an aid to students in planning their course schedules and are only applicable to students seeking a master's degree. They do not appear as official designations on a student's transcript or diploma.

NANOMATERIALS

510/515.621 Nanoparticles*
510/515.622 Micro and Nano Structured Materials and Devices*
510.427 Chemistry of Nanomaterials*
515.615 Physical Properties of Materials*
515.636 Chemical Synthesis and Processing of Advanced Materials
515.730 Materials Science and Engineering Project
515.731 Materials Science and Engineering Project
525.606 Electronic Materials
525.621 Introduction to Electronics and the Solid State
530.445 Introduction to Biomechanics†
530.603 Fundamentals of Microscale Phenomena†
540.403 Colloids and Nanoparticles‡
540.415 Interfacial Science with Applications to Nanoscale Systems‡
585.710 Biochemical Sensors

** 510.xxx courses are offered through the full-time Department of Materials Science & Engineering.*
† 530.xxx courses are offered through the full-time Department of Mechanical Engineering.
‡ 540.xxx courses are offered through the full-time Department of Chemical & Biomolecular Engineering.

615.641 Mathematical Methods for Physics and Engineering
615.746 Nanoelectronics: Physics and Devices
615.747 Sensors and Sensor Systems
615.757 Solid-State Physics

BIOTECHNOLOGY

515.608 Biomaterials II: Host Response and Biomaterials Applications
510.606 Chemical and Biological Properties of Materials*
515.730 Materials Science and Engineering Project
515.731 Materials Science and Engineering Project
530.445 Introduction to Biomechanics†
540.428 Supramolecular Materials and Nanomedicine‡
580.442 Tissue Engineering§
580.641 Cellular Engineering§
585.601 Physiology for Applied Biomedical Engineering I
585.602 Physiology for Applied Biomedical Engineering II
585.615 Mathematical Methods for Applied Biomedical Engineering
585.708 Biomaterials
585.709 Biomechanics of Cell and Stem Cells
585.710 Biochemical Sensors

OTHER ELECTIVES

515.603 Materials Characterization
515.605 Electrical, Optical and Magnetic Properties
515.615 Physical Properties of Materials*
515.634 Fundamentals of Metamaterials
515.635 Mechanical Properties of Materials
515.656 Additive Manufacturing
515.657 Additive Manufacturing Materials and Processes
515.658 Design for Additive Manufacturing
515.730/731 Materials Science and Engineering - EP Project

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

§ *580.xxx courses are offered through the full-time Department of Biomedical Engineering.*

MECHANICAL ENGINEERING

- **Master of Mechanical Engineering**
  Focus Areas: Manufacturing; Solids/Mechanics of Materials; Thermofluids; Robotics and Controls*
- **Post-Master's Certificate in Mechanical Engineering**

The part-time Mechanical Engineering program is designed for working engineers who want to enhance their effectiveness in a complex and rapidly evolving technological and organizational environment. The program broadens and strengthens students' understanding of traditional fundamentals but also introduces them to contemporary applications and technologies.

Courses are offered primarily online, with a few being offered at the Applied Physics Laboratory and the Homewood campus.

PROGRAM COMMITTEE

JAAFAR A. EL-AWADY, PROGRAM CHAIR
Associate Professor of Mechanical Engineering
JHU Whiting School of Engineering

**A focus area must be chosen for this program.*

REQUIREMENTS

MASTER'S

ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include a bachelor's degree in Mechanical Engineering or a closely related technical discipline. Enrolled students typically have earned a grade point average of at least 3.3 on a 4.0 scale (B+ or above) of their undergraduate studies, though this is not a requirement for admission, nor is it a guarantee. Transcripts from all college studies must be submitted. When reviewing an application, the candidate's academic and professional background will be considered in its totality, and decisions are made on a case-by-case basis.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students are required to choose a focus area to follow. The curriculum consists of one core course in mathematics, two core courses for the focus area, three courses chosen among those listed for the student's focus area, and four other part-time or full-time courses. At least two of these four courses must be from a core engineering discipline, and at most two can be chosen from the Technical Management and Systems Engineering areas. At least one computationally oriented course is strongly recommended as an elective. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post-Master's Certificate in Mechanical Engineering.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. Only grades of B– or above can count toward the post-master's certificate. Focus areas are not applicable to students pursuing certificates. Students are free to choose any six courses offered by the Mechanical Engineering program. All course selections are subject to advisor approval.

COURSES

CORE COURSE

535.641 Mathematical Methods for Engineers

This course must be taken in the first semester of the student's program, unless the advisor explicitly allows the student to do otherwise.

RECOMMENDED

SELECT ONE

At least one computationally oriented course is strongly recommended as an elective.

535.609 Topics in Data Analysis
535.610 Computational Methods of Analysis
535.613 Structural Dynamics and Stability
535.631 Introduction to Finite Element Methods
535.632 Applied Finite Elements
565.616 Applied Finite Element Methods

COURSES BY FOCUS AREA

Students are required to choose one of four focus areas: Manufacturing, Solids/Mechanics of Materials, Thermofluids, Robotics and Controls. The focus area selected does not appear as an official designation in the student transcript. Each focus area has five required courses. Of these courses, at least two marked by an asterisk (*) must be completed. Post-master's certificate students are not limited to one focus area but can choose their courses among all the courses offered by the program.

SOLIDS/MECHANICS OF MATERIALS

*COURSES FOR THE FOCUS AREA (SELECT FIVE–AT LEAST TWO MUST BE MARKED WITH AN *)*

535.606 Advanced Strength of Materials*
535.609 Topics in Data Analysis
535.612 Intermediate Dynamics
535.613 Structural Dynamics and Stability
535.623 Intermediate Vibrations*
535.627 Computer-Aided Design
535.631 Introduction to Finite Element Methods
535.632 Applied Finite Elements
535.654 Theory and Applications of Structural Analysis*
535.660 Precision Mechanical Design
535.684 Modern Polymeric Materials
535.691 Mechanics of Molecules and Cells
535.711 Symmetries of Crystalline Solids*
535.720 Analysis and Design of Composite Structures
535.731 Engineering Materials: Properties and Selection
565.616 Applied Finite Element Methods
585.709 Biomechanics of Cell and Stem Cells
585.720 Orthopedic Biomechanics

THERMOFLUIDS

COURSES FOR THE FOCUS AREA
*(SELECT FIVE–AT LEAST TWO MUST BE MARKED WITH AN *)*

535.609 Topics in Data Analysis
535.614 Fundamentals of Acoustics
535.621 Intermediate Fluid Dynamics*
535.629 Energy Engineering
535.633 Intermediate Heat Transfer*
535.634 Applied Heat Transfer*
535.650 Combustion
535.652 Thermal Systems Design and Analysis
535.662 Energy and the Environment
535.675 Thermal Sciences for the Built Environment
535.712 Applied Fluid Dynamics*
535.736 Applied Computational Fluid Mechanics
535.737 Multiscale Modeling and Simulation of Mechanical Systems
585.709 Biomechanics of Cell and Stem Cells

MANUFACTURING

COURSES FOR THE FOCUS AREA
*(SELECT FIVE–AT LEAST TWO MUST BE MARKED WITH AN *)*

515.656 Additive Manufacturing
535.623 Intermediate Vibrations
535.627 Computer-Aided Design
535.628 Computer-Integrated Design and Manufacturing*
535.630 Kinematics and Dynamics of Robots
535.633 Intermediate Heat Transfer
535.642 Control Systems for Mechanical Engineering Applications
535.659 Manufacturing Systems Analysis*
535.660 Precision Mechanical Design*
535.672 Advanced Manufacturing Systems
535.673 Mechanized Assembly: Hardware and Algorithms*
535.684 Modern Polymeric Materials
535.727 Advanced Machine Design

ROBOTICS AND CONTROLS

COURSES FOR THE FOCUS AREA
*(SELECT FIVE–AT LEAST TWO MUST BE MARKED WITH AN *)*

525.609 Continuous Control Systems
535.609 Topics in Data Analysis
535.612 Intermediate Dynamics
535.622 Robot Motion Planning*
535.623 Intermediate Vibrations
535.627 Computer-Aided Design
535.628 Computer-Integrated Design and Manufacturing
535.630 Kinematics and Dynamics of Robots*
535.635 Introduction to Mechatronics
535.642 Control Systems for Mechanical Engineering Applications*
535.645 Digital Control and Systems Applications
535.659 Manufacturing Systems Analysis
535.660 Precision Mechanical Design
535.673 Mechanized Assembly: Hardware and Algorithms
535.724 Dynamics of Robots and Spacecraft*
535.726 Robot Control
535.782 Haptic Applications

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

SPACE SYSTEMS ENGINEERING

- **Master of Science in Space Systems Engineering**
  Focus Areas: Technical or Leadership/Management*

The Space Systems Engineering program is intended for existing or aspiring space engineering professionals and will greatly expand their knowledge, capabilities, and opportunities, preparing students for rewarding careers in the space industry. Students are exposed to all the technical disciplines encountered throughout the space systems development life cycle including mission formulation, concept development, design, integration, test, and mission operations. Students are introduced to the formal systems engineering method, first as applied to entire space missions, and then with ever-increasing technical rigor, as applied to flight and ground systems and subsystems. A diverse array of technical electives permits students to tailor their curriculum to suit their individual professional interests. Students then have the opportunity to immerse themselves into case studies of current topics drawn from relevant real-world programs. Additionally, a hands-on small-spacecraft integration and test course allows students to work on a real spacecraft using modern test equipment and spacecraft control software in a laboratory environment. Program faculty are top subject matter experts and practitioners from across the space community, including the Johns Hopkins University Applied Physics Laboratory.

Courses are offered at the Applied Physics Laboratory in a virtual-live format as well as online.

PROGRAM COMMITTEE

PATRICK W. BINNING, PROGRAM CHAIR
Principal Professional Staff
JHU Applied Physics Laboratory

WILLIAM S. DEVEREUX, PROGRAM COORDINATOR
Principal Professional Staff
JHU Applied Physics Laboratory

BRIGADIER GENERAL MARK BAIRD
United States Air Force

HANS KOENIGSMANN
Vice President, Build and Flight Reliability
Space X

JOE PELLICCIOTTI
Acting Deputy Chief Engineer
NASA HQ

HELMUT SEIFERT
Principal Professional Staff
JHU Applied Physics Laboratory

**A focus area is not required for this program.*

REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include an undergraduate or graduate degree in a quantitative discipline (e.g., engineering, computer science, mathematics, physics, or equivalent) from a regionally accredited college or university. Applicants must show competency in (1) calculus, (2) physics, and (3) computer programming, which must be demonstrated through undergraduate or graduate coursework or equivalent work experience. In addition to this requirement, applicants will typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered. As part of the admission process, the chair or the program coordinator may interview candidates to better evaluate their application.

DEGREE REQUIREMENTS

A total of ten courses (at least three at the 700-level) must be completed within five years. The curriculum consists of five core courses and five others chosen by the student in consultation with their advisor. The curriculum is designed to provide maximum flexibility to students, enabling them to customize their five non-core classes based on their educational needs and career goals. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All courses in the Space Systems Engineering program may be completed remotely (online or via virtual-live), except for the program capstone (675.710), which includes a requirement that students attend a specified residency weekend at the APL campus to complete the laboratory component.

COURSES

CORE COURSES

675.600 Systems Engineering for Space
675.601 Fundamentals of Engineering Space Systems I
675.602 Fundamentals of Engineering Space Systems II
675.701 Applications of Space Systems Engineering
675.710 Small Satellite Development and Experimentation

COURSES BY FOCUS AREA

Non-core SSE electives are divided into two focus areas. The first is the Technical focus area, which emphasizes rigorous understanding of systems and subsystems in terms of fundamental engineering disciplines. The second is the Leadership/Management focus area, which prepares students for project/program management roles or leading technical teams and organizations. Students are not required to declare a focus area, and can choose their electives from one or both areas according to their interests and needs. If a student wishes to take an Engineering for Professionals course not listed in the electives below, they should consult their advisor.

TECHNICAL

SSE PROGRAM ELECTIVES

675.640 Satellite Communications Systems
675.650 Mathematics for Space Systems
675.691 Electro-Optical Space Systems
675.711 Ground System Engineering and Mission Operations
675.751 Space Weather and Space Systems
675.752 Attitude Determination and Control of Space Systems
675.754 Flight Software for Space Systems
675.756 Antenna Design for Space Systems
675.761 Reliability Engineering and Analysis for Space Missions
675.768 Spacecraft Integration and Test
675.771 Space Mission Design and Navigation
675.800 Directed Studies in Space Systems Engineering

PRE-APPROVED ELECTIVES FROM OTHER EP PROGRAMS

525.609 Continuous Control Systems
525.616 Communication Systems Engineering
525.645 Modern Navigation Systems
525.666 Linear System Theory
565.604 Structural Mechanics
605.601 Foundations of Software Engineering
605.604 Object-Oriented Programming with C++
605.611 Foundations of Computer Architecture
615.665 Modern Physics
615.671 Principles of Optics
615.747 Sensors and Sensor Systems
615.769 Physics of Remote Sensing

LEADERSHIP/MANAGEMENT

595.660 Planning and Managing Projects
595.740 Assuring Success of Aerospace Programs
595.793 Applied Innovation for Technical Professionals
645.667 Management of Systems Projects
645.742 Management of Complex Systems
645.757 Foundations of Modeling and Simulation in Systems Engineering
645.761 Systems Architecting
645.767 System Conceptual Design
645.768 System Design and Integration
645.769 System Test and Evaluation

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

SYSTEMS ENGINEERING

- **Master of Science in Systems Engineering**
- **Master of Science in Engineering in Systems Engineering (ABET-accredited)**
- **Post-Master's Certificate in Systems Engineering**
- **Graduate Certificate in Systems Engineering**

The part-time Systems Engineering program provides students with in-depth knowledge and technical skills that prepare them to further their careers within industry and government. The program addresses the needs of engineers and scientists engaged in all aspects of analysis, design, integration, production, and operation of modern systems. Instructors are practicing systems engineers who employ lectures and readings on theory and practice, and present realistic problem scenarios in which students, individually and collaboratively, apply principles, tools, and skills.

Courses are offered online as well as at the Applied Physics Laboratory and Southern Maryland Higher Education Center.

PROGRAM COMMITTEE

RONALD R. LUMAN, PROGRAM CHAIR
Principal Professional Staff
JHU Applied Physics Laboratory

DAVID A. FLANIGAN, VICE CHAIR
Principal Professional Staff
JHU Applied Physics Laboratory

LARRY D. STRAWSER, INCOSE AND ASEE LIAISON
Adjunct Professor
JHU Whiting School of Engineering

CHRISTIAN UTARA, PROGRAM QUALITY COORDINATOR
National Director, Air 4.11
Rapid Capability Engineering
+ Integration Department

JAMES COOLAHAN, PARTNERSHIP DEVELOPMENT AND OUTREACH MANAGER
Chief Technology Officer
Coolahan Associates, LLC

STEVEN M. BIEMER
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WILLIAM B. CROWNOVER
Principal Professional Staff
JHU Applied Physics Laboratory

CONRAD J. GRANT
Principal Professional Staff
JHU Applied Physics Laboratory

BENJAMIN F. HOBBS
Theodore M. and Kay W. Schad
Professor of Environmental Management
JHU Whiting School of Engineering

JERRY A. KRILL
Principal Professional Staff
JHU Applied Physics Laboratory

EDWARD A. SMYTH
Principal Professional Staff
JHU Applied Physics Laboratory (retired)

REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include a degree in a science or engineering field. In addition to this requirement, a minimum of one year of relevant full-time work experience in the field is required, and a detailed work résumé and transcripts from all college studies must be submitted. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. When reviewing an application, the candidate's academic and professional background will be considered.

The Systems Engineering program offers two degree distinctions—a Master of Science in Engineering (MSE) and a Master of Science (MS). In order to be admitted into the MSE program, applicants need to hold a degree issued by a program accredited by the Engineering Accreditation Commission (EAC) of ABET, http://www.abet.org. Students admitted without a Bachelor of Science degree from an EAC of ABET-accredited program (or who did not complete the prerequisites that meet all of the EAC of ABET-accreditation requirements for attainment of student outcomes and for sufficient math, science, and engineering design at the Bachelor of Science level) will receive a regionally accredited Master of Science degree. There is no difference in the curriculum for the MSE and MS programs.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. The curriculum consists of seven or eight core courses and two or three electives, depending on whether the master's project or the master's thesis is selected.

Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

JHU SYSTEMS ENGINEERING PROGRAM EDUCATIONAL OBJECTIVES

Within 2–5 years after graduation, Master of Science in Engineering in System Engineering graduates of Johns Hopkins University will:

1. Attain programmatic or technical leadership roles in systems engineering or the management of complex systems.
2. Employ systems engineering methods and tools throughout the life cycle of complex systems.

JHU SYSTEMS ENGINEERING STUDENT OUTCOMES

Upon completing the Master of Science in Engineering in Systems Engineering Program, students will be able to:

1. Apply technical knowledge in mathematics, science, and engineering to lead the realization and evaluation of complex systems and systems of systems.
2. Demonstrate the ability to conceive of, gather user needs and requirements for, design, develop, integrate, and test complex systems by employing systems engineering thinking and processes within required operational and acquisition system environments.
3. Understand and utilize the life cycle stages of systems development from concept development through manufacturing and operational maintenance.
4. Lead and participate in interdisciplinary teams to manage the cost-effective systems.
5. Communicate complex concepts and methods in spoken and written format.
6. Demonstrate awareness and capability in employing tools and techniques in the systems engineering process.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post-Master's Certificate in Systems Engineering.

POST-MASTER'S CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. The curriculum consists of four advanced courses (645.742, 645.753, 645.761, 645.771) and two electives. The two electives can be two semesters of an independent systems engineering research project leading to a paper suitable for submission for publication in a refereed journal, or two 700-level courses in a program approved by the student's advisor. Only grades of B– or above can count toward the post-master's certificate.

GRADUATE CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate-level courses, but not necessarily interested in pursuing a full master's degree, are eligible for the Graduate Certificate in Systems Engineering. Applicants are required to meet the same requirements for admission as the master's degree.

Applicants must have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Significant relevant work experience or a graduate degree in a relevant technical discipline may be considered in lieu of meeting the GPA requirement.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare their intention prior to completing the certificate.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. The curriculum consists of the first six core courses. Only grades of B– or above can count toward the graduate certificate.

COURSES

REQUIRED COURSES FOR MASTER'S DEGREES

(The first six courses are required for the Graduate Certificate.)

645.662 Introduction to Systems Engineering
645.667 Management of Systems Projects
645.764 Software Systems Engineering
645.767 System Conceptual Design
645.768 System Design and Integration
645.769 System Test and Evaluation
645.800 Systems Engineering Master's Project OR
645.801 Systems Engineering Master's Thesis AND
645.802 Systems Engineering Master's Thesis

ELECTIVES

Students earning a master's degree must take three electives (or two if students take the two-semester thesis option) from the list of courses by track below. Other JHU/WSE courses may be accepted as electives with the approval of the student's advisor. The tracks below represent related groups of courses that are relevant for students with interests in the selected areas.

SYSTEMS

645.631 Introduction to Model Based Systems Engineering
645.632 Applied Analytics for Model Based Systems Engineering
645.669 Systems Engineering of Deployed Systems
645.742 Management of Complex Systems
645.753 Enterprise Systems Engineering
645.761 Systems Architecting
645.771 System of Systems Engineering

CYBERSECURITY

635.611 Principles of Network Engineering
635.672 Privacy Engineering
635.673 Critical Infrastructure
635.676 Cybersecurity in Information Systems
635.682 Website Development
635.683 E-Business: Models, Architecture, Technologies, and Infrastructure
695.601 Foundations of Information Assurance
695.621 Public Key Infrastructure and Managing E-Security
695.744 Reverse Engineering and Vulnerability Analysis

HUMAN SYSTEMS

635.661 Principles of Human–Computer Interaction
645.621 Engineering and Measuring Influence
645.650 Foundations of Human Systems Engineering
645.651 Integrating Humans and Technology
645.754 Social and Organizational Factors in Human Systems Engineering
645.755 Methods in Human-System Performance Measurement and Analysis

MODELING AND SIMULATION

625.603 Statistical Methods and Data Analysis
645.756 Metrics, Modeling, and Simulation for Systems Engineering
645.757 Foundations of Modeling and Simulation in Systems Engineering
645.758 Advanced Systems Modeling and Simulation

PROJECT MANAGEMENT

595.627 Advanced Concepts in Agile Technical Management
595.661 Technical Group Management
595.665 Communications in Technical Organizations
595.666 Financial and Contract Management

SOFTWARE SYSTEMS

605.604 Object-Oriented Programming with C++
605.607 Agile Software Development Methods
605.608 Software Project Management
605.704 Object-Oriented Analysis and Design
605.705 Software Safety
605.708 Tools and Techniques of Software Project Management

COURSES FOR POST-MASTER'S CERTIFICATE

REQUIRED

645.742 Management of Complex Systems

645.753 Enterprise Systems Engineering

645.761 Systems Architecting

645.771 System of Systems Engineering

ELECTIVES (SELECT ONE)

645.803 Post-Master's Systems Engineering Research Project AND
645.804 Post-Master's Systems Engineering Research Project

Two approved 700-level courses

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

TECHNICAL MANAGEMENT

- **Master of Science in Technical Management**
  Focus Areas: Organizational Management; Project Management; Project/Organizational Management; Quality Management; or Technical Innovation Management*
- **Post-Master's Certificate in Technical Management**
- **Graduate Certificate in Technical Management**

The part-time Technical Management program prepares ethically grounded, technically competent professional leaders with the technical, managerial, and leadership skills to produce innovative solutions to technical organizations' challenges. The program focuses on developing specialized managerial skills for working professionals. The curriculum prepares students to take on leadership roles as technical functional managers, project managers, and program managers. The program blends lectures on theory and practice presented by experienced technical senior leaders and executives. Presentation of realistic challenges enables students to consider various management roles, dealing with problems and making decisions that are typically required of technical managers. Emphasis is on the blend of strategy, leadership, administrative, business, and interpersonal skills required for the successful management of continually changing high-technology organizations and projects.

Courses are offered in person at the Applied Physics Laboratory as well as in the distant learning environment. The program can be completed online.

TECHNICAL MANAGEMENT AND ENGINEERING MANAGEMENT PROGRAMS COMMITTEE

TIM COLLINS
Programs Chair, Technical Management and Engineering Management
JHU Whiting School of Engineering

RICK BLANK
Programs Coordinator, Technical Management and Engineering Management
JHU Whiting School of Engineering

ANN KEDIA
Principal Professional Staff
JHU Applied Physics Laboratory

DAN REGAN
Director, Federal Healthcare Business Development
CACI International, Inc.

PAMELA SHEFF
Director, Master of Science in Engineering Management Program
JHU Whiting School of Engineering

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**A focus area must be chosen for this program.*

REQUIREMENTS

MASTER OF SCIENCE

ADMISSION REQUIREMENTS

Applicants must meet the general requirements for admission to graduate study, as outlined in the Admission Requirements section on page 3. The applicant's prior education must include a degree in a science or engineering field. In addition to this requirement, a minimum of two years of relevant full-time work experience in the field is required, and a detailed work résumé and transcripts from all college studies must be submitted. Applicants typically have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies.

DEGREE REQUIREMENTS

Ten courses must be completed within five years. Students must choose a focus area to follow. The curriculum consists of a combination of core courses and electives based on the chosen focus area; at least three of the ten courses must be 700-level courses. Only one C-range grade (C+, C, or C–) can count toward the master's degree. All course selections are subject to advisor approval.

POST-MASTER'S CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who have already completed a master's degree in a closely related technical discipline are eligible to apply for the Post-Master's Certificate in Technical Management.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least four of the six courses must be from the program (595.xxx). Two electives may be taken from other programs with approval from the program chair or the program coordinator. Only grades of B– or above can count toward the post-master's certificate. Focus areas are not available for students pursuing certificates. All course selections are subject to advisor approval.

GRADUATE CERTIFICATE

ADMISSION REQUIREMENTS

Applicants who are interested in taking graduate-level courses, but not necessarily interested in pursuing a full master's degree are eligible for the Graduate Certificate in Technical Management. Applicants are required to meet the same requirements for admission as the master's degree.

Applicants must have earned a grade point average of at least 3.0 on a 4.0 scale (B or above) in the latter half of their undergraduate studies. Significant relevant work experience or a graduate degree in a relevant technical discipline may be considered in lieu of meeting the GPA requirement.

If the student should decide to pursue the full master's degree, all courses will apply to the master's degree provided they meet program requirements and fall within a five-year time limit. The student must declare their intention prior to completing the certificate.

CERTIFICATE REQUIREMENTS

Six courses must be completed within three years. At least four of the six courses must be from the program (595.xxx). Two electives may be taken from other programs with approval from the program chair or the program coordinator. Only grades of B– or above can count toward the graduate certificate. Focus areas are not available for students pursuing certificates. All course selections are subject to advisor approval.

COURSES

CORE COURSES

Students are required to take the core courses listed in their focus areas. Electives will round out the ten-course requirement.

COURSES BY FOCUS AREA

The focus areas offered represent related groups of courses that are relevant for students with interests in the selected areas. The focus areas are presented as an aid to students in planning their course schedules and are only applicable to students seeking a master's degree. They do not appear as official designations on a student's transcript or diploma.

ORGANIZATIONAL MANAGEMENT

CORE COURSES

595.660 Planning and Managing Projects
595.661 Technical Group Management
595.663 Technical Personnel Management
595.664 Project Planning and Control
595.665 Communications in Technical Organizations
595.666 Financial and Contract Management
595.762 Management of Technical Organizations

Plus three *electives (two at the 700-level)*

The Organizational Management focus area prepares the student to lead technical staff in engineering organizations. Coursework includes the management of technical organizations as well the management of technical staff. Students who have graduated from this program often are employed as technical group leaders.

PROJECT MANAGEMENT

CORE COURSES

595.660 Planning and Managing Projects
595.661 Technical Group Management
595.664 Project Planning and Control
595.665 Communications in Technical Organizations
595.666 Financial and Contract Management
645.662 Introduction to Systems Engineering
645.764 Software Systems Engineering

***Plus three** electives (two at the 700-level)*

In this focus area students acquire the skills needed to manage/lead complex technical engineering projects. Graduates find employment as project managers on complex aerospace, IT, and biomedical projects.

PROJECT/ORGANIZATIONAL MANAGEMENT

CORE COURSES

595.660 Planning and Managing Projects
595.661 Technical Group Management
595.663 Technical Personnel Management
595.664 Project Planning and Control
595.665 Communications in Technical Organizations
595.666 Financial and Contract Management
595.762 Management of Technical Organizations
645.662 Introduction to Systems Engineering
645.764 Software Systems Engineering

***Plus one** 700-level elective*

Students who select this focus area may not yet have decided whether they want to become line or project managers. This focus area allows the student, by means of electives, to concentrate on their chosen career path.

QUALITY MANAGEMENT

CORE COURSES

595.660 Planning and Managing Projects
595.664 Project Planning and Control
595.740 Assuring Success of Aerospace Programs
595.742 Foundations of Quality Management
645.662 Introduction to Systems Engineering
645.764 Software Systems Engineering

***Plus four** electives*

Because complex technical programs often need to focus on delivering engineering products to very high standards, this focus area offers courses on how to develop engineering products to the highest standards. Coursework includes the introduction to AS9100.

TECHNICAL INNOVATION MANAGEMENT

CORE COURSES

595.660 Planning and Managing Projects
595.661 Technical Group Management
595.665 Communications in Technical Organizations
595.666 Financial and Contract Management
595.762 Management of Technical Organizations
595.766 Advanced Technology
595.793 Applied Innovation for Technical Professionals

***Plus three** electives*

For those students who aspire to become entrepreneurs or lead the innovation efforts in their companies, this focus area offers an introduction on how to lead these efforts. Graduates of this program have in the past been involved with start-up companies.

ELECTIVES

595.627 Advanced Concepts in Agile Technical Management
595.661 Technical Group Management
595.663 Technical Personnel Management
595.664 Project Planning and Control
595.665 Communications in Technical Organizations
595.666 Financial and Contract Management
595.731 Business Law for Technical Professionals
595.740 Assuring Success of Aerospace Programs
595.742 Foundations of Quality Management
595.762 Management of Technical Organizations
595.766 Advanced Technology
595.781 Executive Technical Leadership
595.793 Applied Innovation for Technical Professionals
595.802 Directed Studies in Technical Management
645.662 Introduction to Systems Engineering
645.764 Software Systems Engineering
645.767 System Conceptual Design
645.768 System Design and Integration
645.769 System Test and Evaluation

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

COURSE DESCRIPTIONS

Please refer to the course schedule (ep.jhu.edu/schedule) published each term for exact dates, times, locations, fees, and instructors.

MATERIALS SCIENCE AND ENGINEERING

515.601 Structure and Properties of Materials

Topics include types of materials, bonding in solids, basic crystallography, crystal structures, tensor properties of materials, diffraction methods, crystal defects, and amorphous materials.

Instructor(s): Farias

515.602 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, and glass transition.

Instructor(s): Farrar-Gaines

515.603 Materials Characterization

This course will describe a variety of techniques used to characterize the structure and composition of engineering materials, including metals, ceramics, polymers, composites, and semiconductors. The emphasis will be on microstructural characterization techniques, including optical and electron microscopy, x-ray diffraction, and acoustic microscopy. Surface analytical techniques, including Auger electron spectroscopy, secondary ion mass spectroscopy, x-ray photoelectron spectroscopy, and Rutherford backscattering spectroscopy. Real-world examples of materials characterization will be presented throughout the course, including characterization of thin films, surfaces, interfaces, and single crystals.

Instructor(s): McGuiggan

515.605 Electrical, Optical and Magnetic Properties

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. Emphasis will be placed on both fundamental principles and applications in contemporary materials technologies.

Prerequisite(s): EN.515.601 or equivalent.

Course Note(s): Please note that this 515 course is also listed as a 510 course in the full-time program. It is the same course. Part-time students should register for the 515 course.

515.606 Chemical and Biological Properties of Materials

An introduction to 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.

Course Note(s): Please note that this 515 course is also listed as a 510 course in the full-time program. It is the same course. Part-time students should register for the 515 course. Recommended Course Background: undergraduate chemistry and biology or permission of instructor.

515.608 Biomaterials II: Host Response and Biomaterials Applications

This course focuses on the interaction of biomaterials with the biological system and applications of biomaterials. Topics include host reactions to biomaterials and their evaluation, cell-biomaterials interaction, biomaterials for tissue engineering applications, biomaterials for controlled drug and gene delivery, biomaterials for cardiovascular applications, biomaterials for orthopedic applications, and biomaterials for artificial organs.

Course Note(s): Please note that this 515 course is also listed as a 510 course in the full-time program. It is the same course. Part-time students should register for the 515 course.

515.615 Physical Properties of Materials

A detailed survey of the relationship between materials properties and underlying microstructure. Structure/property/processing relationships will be examined across a wide spectrum of materials including metals, ceramics, polymers and biomaterials, and properties including electrical, magnetic, optical, thermal, mechanical, chemical and biocompatibility.

Course Note(s): Please note that this 515 course is also listed as a 510 course in the full-time program. It is the same course. Part-time students should register for the 515 course.

515.616 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.

Instructor(s): Sample

515.617 Nanomaterials

Nanomaterials is a survey course that covers concepts and the associated relevant physics and materials science of what makes nanoscale materials so unique. We'll learn about nanoscale characterization (electron and probe microscopy), fabrication at the nanoscale (self-assembly and top-down fabrication), and many current applications of nanomaterials across broad areas from medicine to defense. This course will take an in-depth look at nanomaterials discussed in Introduction to Nanotechnology; however, it stands alone with no prerequisite.

Instructor(s): Sample

510.421/515.621 Nanoparticles

Nanoparticles - one-dimensional materials with diameters of nearly atomic dimension - are one of the most important classes of nanostructured materials because their unusual properties that often differ significantly from bulk materials. This course will explore the synthesis, structure and properties of nanoparticles. Applications of nanoparticles in medicine, optics, sensing, and catalysis will be discussed, with an emphasis will be on metal nanoparticles and semiconductor quantum dots.

Course Note(s): Part-time students should register for the 515 course.

510/515.622 Micro and Nano Structured Materials and Devices

Almost every material's 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 (MEMS) devices

Course Note(s): Part-time students should register for the 515 course.

515.634 Fundamentals of Metamaterials

This course introduces the student to the field of metamaterials. The course will begin with a review of basic electromagnetic wave propagation and interaction with matter. The remainder of the course will discuss how metamaterials can be utilized to manipulate electromagnetic fields. Topics will include negative refractive index, perfect lensing, metasurfaces, artificial magnetic conductors, and absorbers.

Instructor(s): Strikwerda

515.635 Mechanical Properties of Materials

This course will consist of a detailed study of the mechanical properties of materials. Topics covered will include stress-strain behavior, elastic and plastic deformation mechanisms, failure mechanisms in quasi-static and dynamic loading conditions, and microstructure-properties relationships. These topics will be discussed as applied to metallic, ceramic, polymeric, and composite materials at bulk and nano scales. The course will also introduce destructive and non-destructive mechanical testing methods.

Course Note(s): Please note that this 515 course is also listed as a 510 course in the full-time program. It is the same course. Part-time students should register for the 515 course.

Instructor(s): Farias

515.636 Chemical Synthesis and Processing of Advanced Materials

This is a treatise course on chemical processing of materials. The primary objective of this course is to provide an introduction to various chemical synthesis and formulation techniques for the study of advanced materials including metals, alloys, semiconductors, ceramics, carbons, polymers, coatings, thin films, nanoparticles, and nanostructured materials. The course will discuss both established chemical processing methods and recent advances in materials synthesis and fabrication. Other topics to be covered include thermodynamics and kinetics in chemistry, structure-property relations, and materials characterization techniques.

Instructor(s): Zhang

515.656 Additive Manufacturing

Additive manufacturing (AM), also known as 3D printing, is a disruptive technology that has received significant attention in recent years in both the popular press and the manufacturing industry. While the current and potential future applications for this technology are impressive and imaginative, it is often very difficult to separate the hype of additive manufacturing from the reality of additive manufacturing. This survey class will cover additive manufacturing processes, the advantages and limitations of these processes (especially with respect to traditional subtractive processes), and practical considerations such as material properties and design for additive manufacturing. Both polymer and metal AM technologies will be included. Recent implementations of additive manufacturing, such as those in the aerospace and health care industries, will be presented extensively throughout the class as study cases. Popular press articles and technical papers on AM will be reviewed and discussed. Students taking this class will be expected to participate actively and bring to the class real or potential applications of AM in their workplaces. The final grade will be based on participation, assigned exercises and readings, and two in-class presentations.

Instructor(s): Slotwinski

515.657 Additive Manufacturing Materials and Processes

This class builds on the material covered in the Additive Manufacturing (AM) overview class (515.656) and previous Material Science & Engineering courses such as Thermodynamics and Kinetics of Materials (515.602). Here we will examine the closely linked topics of AM materials and AM processes, with a strong focus on metal materials and the laser-based powder bed fusion processes. Topics will include conventional vs. AM materials, meltpool phenomena including solidification, kinetics and solid state kinetics, post-process thermal treatments, the process-properties relationship, in-situ process sensing, indirect process measurement methods and process modeling.

Instructor(s): Slotwinski

515.658 Design for Additive Manufacturing

This class builds on material covered in the Additive Manufacturing (AM) overview class (515.656) and previous Materials Science and Engineering courses such as Thermodynamics and Kinetics of Materials (515.602). We will learn the design process and design for AM specifically. Students will determine applications and opportunities to apply AM technology and also learn how to evaluate AM designs. Topics will include work flow decisions to determine AM application, design considerations for metal and polymer AM, design for multi-material and functional assembly applications, and AM design evaluation.

Prerequisite(s): 515.656 Additive Manufacturing.

Corequisite(s): 515.656 Additive Manufacturing.

Instructor(s): Crane

515.730 Materials Science and Engineering – EP Project

This course is an individually tailored, supervised project that offers research experience through work on a special problem related to each student's field of interest. Upon completion of this course, a written essay must be submitted. The faculty advisor will approve the final essay.

Prerequisite(s): All other coursework should be completed before this project begins (or at least completed concurrently with this project). Consent of advisor is required.

515.731 Materials Science and Engineering – EP Project

This course is an individually tailored, supervised project that offers research experience through work on a special problem related to each student's field of interest. Upon completion of this course, a written essay must be submitted. The faculty advisor will approve the final essay.

Prerequisite(s): All other coursework should be completed before this project begins (or at least completed concurrently with this project). Consent of advisor is required.

515.800 Independent Study in Materials Science and Engineering

Independent study allows students to take a specialty course on a topic not currently offered within EP but is related to the expertise of a faculty member. Students enrolled in this course are expected to meet with their instructor on a weekly basis and to complete assignments as required including but not restricted to homework, tests and topical essays. Arrangements for this course should be made between the student and the instructor. Final approval is required from the Program Chair. Generally, only one semester of Independent Study will be approved, but a second semester will be granted with justification.

Prerequisite(s): All other coursework should be completed before this project begins (or at least completed concurrently with this project). Program Chair approval is required.

515.801 Independent Study in Materials Science and Engineering

Second semester of independent study. See description for 515.800.

Prerequisite(s): All other coursework should be completed before this project begins (or at least completed concurrently with this project). Program Chair approval is required.

ELECTRICAL AND COMPUTER ENGINEERING

525.201 Circuits, Devices, and Fields

This course is intended to prepare students lacking an appropriate background for graduate study in electrical and computer engineering. Fundamental mathematical concepts including calculus, differential equations, and linear algebra are reviewed. Circuit theory for linear and nonlinear devices and components is covered. An introduction to electricity and magnetism is presented along with basic wave propagation theory. Finally, Boolean algebra is studied with applications to digital circuit design and analysis.

Prerequisite(s): Two or more semesters of calculus, differential equations, and at least two semesters of calculus-based physics.

Course Note(s): Not for graduate credit.

Instructor(s): Chew, Comberiate, Roddewig, Westgate

525.202 Signals and Systems

This course is intended to prepare students lacking an appropriate background for graduate study in electrical and computer engineering. Signal and system representations and analysis tools in both continuous time and discrete time are covered. Linear time-invariant systems are defined and analyzed. The Fourier transform, the Laplace transform, and the z-transform are treated along with the sampling theorem. Finally, fundamental concepts in probability, statistics, and random processes are considered.

Prerequisite(s): Two or more semesters of calculus and differential equations.

Course Note(s): Not for graduate credit.

Instructor(s): C. L. Edwards, Jennison

525.605 Intermediate Electromagnetics

This course provides a background in engineering electromagnetics required for more advanced courses in the field. Topics include vector calculus, Poisson's and Laplace's equations, Vector potentials, Green's functions, magnetostatics, magnetic and dielectric materials, Maxwell's equations, plane wave propagation and polarization, reflection and refraction at a plane boundary, frequency-dependent susceptibility functions, transmission lines, waveguides, and simple antennas. Practical examples are used throughout the course.

Instructor(s): Thomas, Weiss

525.606 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.

Prerequisite(s): An undergraduate degree in engineering, physics, or materials science; familiarity with materials structures and electronic devices.

Instructor(s): Charles

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

Instructor(s): Boteler, Charles

525.608 Next-Generation Telecommunications

This course examines voice, data, and video communications through emerging technologies. Considerations include the characteristics and security requirements of the information being encoded, bandwidth requirements and limitations, and transmission standards and equipment. Topics will consider the pragmatics facing the communications system engineer including space, weight, and power. The student will review past and present network architectures and apply trade-off decisions when analyzing new system requirements. Topics include brief histories of telecommunications, speech processing, encoding, digitization, signaling, and transmission; broadband, fiber optics, and wireless network architectures; and encryption, privacy, and security issues. New and disruptive technologies are discussed each offering.

Prerequisite(s): Either an undergraduate degree in electrical engineering or 525.616 Communications Systems Engineering, or consent of the instructor.

Instructor(s): Blodgett, Carmody

525.609 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.

Prerequisite(s): Background in linear algebra and linear differential equations.

Instructor(s): Palumbo

525.610 Microprocessors for Robotic Systems

This course examines microprocessors as an integral part of robotic systems. Techniques required for successful incorporation of embedded microprocessor technology are studied and applied to robotic systems. Students will use hardware in a laboratory setting and will develop software that uses features of the microprocessor at a low level to accomplish the real-time performance necessary in robotic applications. Topics will include microprocessor selection, real-time constraints, sensor interfacing, actuator control, and system design considerations.

Prerequisite(s): Experience with C programming and a course in digital systems or computer architecture.

Instructor(s): Sawyer

525.612 Computer Architecture

This course focuses on digital hardware design for all major components of a modern, reduced-instruction-set computer. Topics covered include instruction set architecture; addressing modes; register-transfer notation; control circuitry; pipelining with hazard control; circuits to support interrupts and other exceptions; microprogramming; computer addition and subtraction circuits using unsigned, two's-complement, and excess notation; circuits to support multiplication using Robertson's and Booth's algorithms; circuits for implementing restoring and non-restoring division; square-root circuits; floating-point arithmetic notation and circuits; memory and cache memory systems; segmentation and paging; input/output interfaces; interrupt processing; direct memory access; and several common peripheral devices, including analog-to-digital and digital-to-analog converters. A mini-project is required.

Prerequisite(s): 525.642 FPGA Design using VHDL or prior knowledge of a hardware description language for FPGA design.

Instructor(s): Beser

525.613 Fourier Techniques in Optics

In this course, the study of optics is presented from a perspective that uses the electrical engineer's background in Fourier analysis and linear systems theory. Topics include scalar diffraction theory, Fourier transforming and imaging properties of lenses, spatial frequency analysis of optical systems, spatial filtering and information processing, and holography. The class discusses applications of these concepts in non-destructive evaluation of materials and structures, remote sensing, and medical imaging.

Prerequisite(s): An undergraduate background in Fourier analysis and linear systems theory.

Instructor(s): Young

525.614 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(s): A working knowledge of multi-variable calculus, Fourier transforms, and linear systems theory.

Instructor(s): Banerjee, Fry, Iwarere, Murphy

525.615 Embedded Microprocessor Systems

This course applies microprocessors as an integral element of system design. Techniques required for successful incorporation of microprocessor technology are studied and used. Hardware and software design considerations that affect product reliability, performance, and flexibility are covered. Students use hardware to gain familiarity with machine and assembly language for software generation, interfacing to a microprocessor at the hardware level, and emulation to check out system performance. Topics include security in embedded systems, case studies in system failures, embedded processors in the space environment, communications protocols, hardware/software system tradeoffs, and SoC/FPGA designs. The course is based on the ARM architecture, and the student will do a series of development and interfacing labs.

Prerequisite(s): Some experience in designing and building digital electronic systems, some familiarity with C programming, and a course in digital systems.

Instructor(s): Crum

525.616 Communication Systems Engineering

In this course, students receive an introduction to the principles, performance and applications of communication systems. Students examine analog modulation/demodulation systems (amplitude - AM, DSB & SSB; and angle - PM & FM) and digital modulation/demodulation systems (binary and M-ary) in noise and interference. Sub-topics include filtering, sampling, quantization, encoding and the comparison of coherent & noncoherent detection techniques to improve signal-to-noise ratio (SNR) and bit error rate (BER) performance. Special topics and/or problems will be assigned that provide knowledge of how communication systems work from a system engineering viewpoint in real-world environments.

Prerequisite(s): A working knowledge of Fourier transforms, linear systems, and probability theory. Basic working knowledge of MATLAB.

Instructor(s): Alexander, Choi, Nichols

525.618 Antenna Systems

This course introduces and explains fundamental antenna concepts for both antennas and antenna arrays. Electromagnetic theory is reviewed and applied to antenna elements such as dipoles, loops, and aperture antennas, as well as antenna arrays. Antenna analysis is presented from a circuit theory point of view to highlight concepts such as reciprocity and the implications for transmit and receive radiation patterns. The importance of two-dimensional Fourier transforms is explained and applied to aperture antennas. Basic array constraints are examined through case studies of uniform, binomial, and general amplitude distributions. The concept of beam squint is explained through examination of constant-phase versus constant-time phase shifters. The Rotman lens is discussed as an example of a common beamformer. The class concludes with an explanation of antenna measurements.

Prerequisite(s): 525.605 Intermediate Electromagnetics or 615.642 Electromagnetics or permission of the instructor.

Instructor(s): Weiss

525.619 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(s): 525.627 Digital Signal Processing.

Instructor(s): Nasrabadi

525.620 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(s): Knowledge of intermediate electromagnetics as covered in 525.605 Intermediate Electromagnetics.

Instructor(s): Sequeira

525.621 Introduction to Electronics and the Solid State

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(s): An undergraduate degree in electrical engineering or the equivalent.

Instructor(s): Charles

525.623 Principles of Microwave Circuits

This course addresses foundational microwave circuit concepts and engineering fundamentals. Topics include electromagnetics leading to wave propagation and generation, the transmission line, and impedance/admittance transformation and matching. Mapping and transformation are presented in the development of the Smith Chart. The Smith Chart is used to perform passive microwave circuit design. Microwave networks and s-matrix are presented; Mason's rules is introduced. Circuits are physically designed using microstrip concepts, taking into consideration materials properties, connectors, and other components.

Instructor(s): Abita, Darwish

525.624 Analog Electronic Circuit Design

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.

Prerequisite(s): Undergraduate courses in electricity and magnetism, circuit theory, and linear analysis.

Instructor(s): Houser

525.625 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(s): 525.605 Intermediate Electromagnetics or equivalent.

Instructor(s): Thomas, Willitsford

525.627 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.

Prerequisite(s): A working knowledge of Fourier and Laplace transforms.

Instructor(s): C. L. Edwards, M. L. Edwards, Jennison, R. Lee

525.630 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, deconvolution, 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(s): 525.627 Digital Signal Processing.

Instructor(s): Fry

525.631 Adaptive Signal Processing

This course explores the use of adaptive filtering algorithms and structures to learn the optimal filter or estimator and track time-varying system dynamics in order to improve the performance over static, fixed filtering techniques. Adaptive systems are implemented as part of the coursework with application to digital communications, beamforming, control systems, and interference cancellation. The final project involves creating an adaptive equalizer for digital communications over a time-varying channel.

Prerequisite(s): 525.627 Digital Signal Processing. Some knowledge of probability is helpful.

Instructor(s): Costabile

525.634 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. As interconnect data rates increase, phenomena that have historically been negligible begin to dominate performance, requiring techniques that were not previously necessary. This course is designed to give the students the theoretical and simulation tools needed to determine where signal integrity issues may arise, how to prevent such problems, and how to resolve problems when they arise in practice. A partial list of topics includes distributed circuits and lossless transmission lines, nonideal transmission line effects, crosstalk mitigation, differential pairs and modal analysis, I/O circuits and logic standards, and signal coding and waveshaping techniques.

Prerequisite(s): Thorough knowledge of digital design and circuit theory. Prior coursework in electromagnetics and Laplace transforms will be helpful.

Instructor(s): Bubnash and Pulaha

525.636 Optics and Photonics Laboratory

The objective of this course is to develop laboratory skills in optics and photonics by performing detailed experimental measurements and comparing these measurements to theoretical models. Error analysis is used throughout to emphasize measurement accuracy. A partial list of topics include: geometric optics, optical properties of materials, diffraction, interference, polarization, non-linear optics, fiber optics, non-linear fiber optics, optical detectors (pin, APD, PMT), optical sources (lasers, blackbodies, LEDs), phase and amplitude modulators, lidar, fiber-optic communications, and IR radiometry. The specific experiments will depend on hardware availability and student interest.

Prerequisite(s): 525.605 Intermediate Electromagnetics or equivalent or permission of the instructor.

Instructor(s): Sova

525.638 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.

Prerequisite(s): An undergraduate degree in electrical engineering or the equivalent. Experience with MATLAB and Simulink will be helpful.

Instructor(s): Roddewig

525.640 Satellite Communications Systems

This course presents the fundamentals of satellite communications link design and an in-depth treatment of practical considerations. Existing commercial, civil, and military systems are described and analyzed, including direct broadcast satellites, high throughput 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. The impact of new technology on future systems in this dynamic field is discussed.

Prerequisite(s): 525.616 Communication Systems Engineering or equivalent or permission of the instructor.

Course Note(s): This course is cross-listed with 675.640 Satellite Communications Systems.

Instructor(s): DeBoy

525.641 Computer and Data Communication Networks

This course provides a comprehensive overview of computer and data communication networks, with emphasis on analysis and modeling. Basic communications principles are reviewed as they pertain to communication networks. Networking principles covered include layered network architecture, data encoding, static and multiaccess channel allocation methods (for LAN and WAN), ARQ retransmission strategies, framing, routing strategies, transport protocols, and emerging high-speed networks.

Prerequisite(s): 525.614 Probability and Stochastic Processes for Engineers and 525.616 Communication Systems Engineering, or equivalents.

Instructor(s): Refaei

525.642 FPGA Design Using VHDL

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.

Prerequisite(s): A solid understanding of digital logic fundamentals.

Instructor(s): DuBois, Hourani, Meitzler, Newlander

525.643 Real-Time Computer Vision

This course introduces students to key computer vision techniques for real-time applications. Students will learn to quickly build applications that enable computers to "see," and make decisions based on still images or video streams. Through regular assignments and in class laboratory exercises (students are advised to bring their own laptop to class), students will build real-time systems for performing tasks including object recognition and face detection and recognition. Key computer vision topics addressed in the course include human and machine vision: how does the brain recognize objects?, and what can we emulate?, camera models and camera calibration; edge, line and contour detection; optical flow and object tracking; machine learning techniques; image features and object recognition; stereo vision; 3D vision; face detection and face recognition. Students will be exposed to the mathematical tools that are most useful in the implementation of computer vision algorithms.

Prerequisite(s): Python programming experience, and prior knowledge of linear algebra, geometry, and probability theory is desired.

Instructor(s): Burlina, Drenkow

525.645 Modern Navigation Systems

This course explores the use of satellite, terrestrial, celestial, radio, magnetic, and inertial systems for the real-time determination of position, velocity, acceleration, and attitude. Particular emphasis is on the historical importance of navigation systems; avionics navigation systems for high performance aircraft; the Global Positioning System; the relationships between navigation, cartography, surveying, and astronomy; and emerging trends for integrating various navigation techniques into single, tightly coupled systems.

Instructor(s): Jablonski

525.646 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(s): 525.627 Digital Signal Processing and C programming experience.

Instructor(s): Orr, Wenstrand

525.648 Introduction to Radar Systems

This class introduces the student to the fundamentals of radar system engineering. The radar range equation in its many forms is developed and applied to different situations. Radar transmitters, antennas, and receivers are covered. The concepts of matched filtering, pulse compression, and the radar ambiguity function are introduced, and the fundamentals of radar target detection in a noise background are discussed. Target radar cross-section models are addressed, as well as the effects of the operating environment, including propagation and clutter. MTI and pulsed Doppler processing and performance are addressed. Range, angle, and Doppler resolution/accuracy, as well as fundamental tracking concepts, will also be discussed.

Prerequisite(s): 525.614 Probability and Stochastic Processes for Engineers, 525.627 Digital Signal Processing, a working knowledge of electromagnetics, and familiarity with MATLAB.

Instructor(s): Farthing, Griffith, Lum

525.651 Introduction to Electric Power Systems

This course introduces and explains fundamentals of electrical power systems design and engineering. Phasors and their application to power systems analysis are reviewed. The concept of the per-unit system is introduced and applied to circuit calculations. Transformers and their application to electrical power transmission and distribution systems will be covered. Transmission line parameters, their calculation, and transmission line modeling are introduced. Steady-state operation of transmission lines is modeled and investigated. Power flow analysis computational techniques are covered. Short-circuit analysis and the method of symmetrical components are introduced. The concept of power system protection and the role of automatic relays will be covered. Primary and secondary distribution systems and substations are introduced. Renewable energy generation and the integration of renewable energy into the modern power grid will be introduced.

Prerequisite(s): Course in electrical networks and a course in linear algebra and matrix operations. MATLAB required software.

Course Note(s): Matlab is required for this course.

Instructor(s): Alvandi

525.654 Communications Circuits Laboratory

This online laboratory-based course focuses on modulation/demodulation (MODEM) aspects of wireless communications systems. This course is designed to enhance the student's understanding of fundamental communications waveforms and to present methods commonly used to process them. Students will be exposed to various implementations of MODEM circuits used to process waveforms such as FM, FSK, PSK, and QAM. All work is performed remotely via Internet access to the remote laboratory facility located at the Johns Hopkins University. Following an introduction to this remote laboratory implementation, students will conduct a series of laboratory exercises designed to enhance their understanding of material presented in communications engineering courses. Course modules involve the characterization of waveforms and MODEM circuits through lecture, laboratory exercises, analysis, and online discussion. Materials required for this course include a broadband Internet connection, web browser, word processing software (e.g., MS Word or equivalent), and analysis software (e.g., MATLAB or equivalent) used to process and present data collected.

Prerequisite(s): 525.616 Communication Systems Engineering or consent of the instructor.

Instructor(s): Houser

525.658 Digital VLSI System Design

An introductory course in digital VLSI design in which students design digital CMOS integrated circuits and systems. The class covers transistor, behavioral, and physical level design using a variety of design tools, including circuit simulation with SPICE, logic synthesis with Verilog HDL, physical layout and automated placement and routing. The class culminates in a final project in which each student designs a more complicated digital system from architecture to final layout.

Prerequisite(s): A course in digital design.

Instructor(s): Meitzler

525.659 Mixed-Mode VLSI Circuit Design

This course focuses on transistor-level design of mixed-signal CMOS integrated circuits. After reviewing fundamentals of MOSFET operation, the course will cover design of analog building blocks such as current-mirrors, bias references, amplifiers, and comparators, leading up to the design of digital-to-analog and analog-to-digital converters. Aspects of sub-threshold operation, structured design, scalability, parallelism, low power-consumption, and robustness to process variations are discussed in the context of larger systems. The course will include use of Cadence design software to explore transistor operation and to perform functional-block designs, in the process of incrementally designing a data-converter front-end.

Prerequisite(s): Familiarity with MOSFET and transistor level circuit design fundamentals.

Instructor(s): Elkis

525.661 UAV Systems and Control

This hardware-supplemented course covers the guidance, navigation- and control principles common to many small fixed-wing and multirotor unmanned aerial vehicles (UAVs).

Building on classical control systems and modeling theory, students will learn how to mathematically model UAV flight characteristics and sensors, develop and tune feedback control autopilot algorithms to enable stable flight control, and fuse sensor measurements using extended Kalman filter techniques to estimate the UAV position and orientation. Students will realize these concepts through both simulation and interaction with actual UAV hardware. Throughout the course, students will build a full 6-degree-of-freedom simulation of controlled UAV flight using MATLAB and Simulink. Furthermore, students will reinforce their UAV flight control knowledge by experimenting with tuning and flying actual open-source quadrotor UAVs.

Prerequisite(s): Background in control systems (e.g., 525.609 Continuous Control Systems) and matrix theory along with a working knowledge of MATLAB. Experience using Simulink is desired. Existing familiarity with C programming language, electronics, and microcontrollers will be helpful but is not required.

Instructor(s): Barton, DiGirolamo

525.666 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.

Prerequisite(s): Courses in matrix theory and linear differential equations.

Instructor(s): Pue

525.670 Machine Learning for Signal Processing

This course will focus on the use of machine learning theory and algorithms to model, classify, and retrieve information from different kinds of real world signals such as audio, speech, image, and video.

Prerequisite(s): 525.627 Digital Signal Processing and 525.614 Probability and Stochastic Processes for Engineers

Instructor(s): Chang and Dehak

525.684 Microwave Systems and Receiver Design

This course deals with the practical aspects of RF and microwave systems and components. An overview of radar systems is followed by an introduction to communication systems. The majority of the course treats the linear and nonlinear characteristics of individual components and their relation to receiver system performance. Amplifiers, mixers, antennas, filters, and frequency sources are studied, as well as their impact on receiver performance. Top-level receiver designs for a radar system, a wide-band surveillance system, or a communication system application may be studied. Assignments reinforce the course material and may require use of design software.

Prerequisite(s): An undergraduate degree in electrical engineering or equivalent.

Instructor(s): M. L. Edwards, Kaul, Marks, J. Wilson

525.691 Fundamentals of Photonics

This course provides the essential background in photonics required to understand modern photonic and fiber-optic systems. Fundamental concepts established in this course are necessary for advanced coursework as well. Topics include: electromagnetic optics, polarization and crystal optics, guided-wave optics, fiber optics, photons in semiconductors, semiconductor photon sources and detectors, electro-optics and acousto-optics.

Prerequisite(s): An undergraduate course in electromagnetic theory.

Instructor(s): Sova

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.

Prerequisite(s): Background in linear algebra, such as 625.609 Matrix Theory; in probability, such as 525.614 Probability and Stochastic Processes for Engineers; and in digital communications, such as 525.616 Communication Systems Engineering. Familiarity with MATLAB or similar programming capability.

Instructor(s): Hammons

525.708 Iterative Methods in Communications Systems

Generalization of the iterative decoding techniques invented for turbo codes has led to the theory of factor graphs as a general model for receiver processing. This course will develop the general theory of factor graphs and explore several of its important applications. Illustrations of the descriptive power of this theory include the development of high performance decoding algorithms for classical and modern forward error correction codes (trellis codes, parallel concatenated codes, serially concatenated codes, low-density parity check codes). Additional applications include coded modulation systems in which the error correction coding and modulation are deeply intertwined as well as a new understanding of equalization techniques from the factor graph perspective.

Prerequisite(s): Background in linear algebra, such as 625.609 Matrix Theory; in probability, such as 525.614 Probability and Stochastic Processes for Engineers; and in digital communications, such as 525.616 Communication Systems Engineering. Familiarity with MATLAB or similar programming capability.

Instructor(s): 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.

Prerequisite(s): 525.612 Computer Architecture or equivalent.

525.718 Multirate Signal Processing

Multirate signal processing techniques find applications in areas such as communication systems, signal compression, and sub-band signal processing. This course provides an in-depth treatment of both the theoretical and practical aspects of multirate signal processing. The course begins with a review of discrete-time systems and the design of digital filters. Sample rate conversion is covered, and efficient implementations using polyphase filters and cascade integrator comb (CIC) filters are considered. The latter part of the course treats filter bank theory and implementation, including quadrature mirror, conjugate quadrature, discrete Fourier transform, and cosine modulated filter banks along with their relationship to transmultiplexers.

Prerequisite(s): 525.627 Digital Signal Processing or equivalent and working knowledge of MATLAB.

Instructor(s): Younkins

525.721 Advanced Digital Signal Processing

The fundamentals of statistical signal processing are presented in this course. Topics include matrix factorizations and least squares filtering, optimal linear filter theory, classical and modern spectral estimation, adaptive filters, and optimal processing of spatial arrays.

Prerequisite(s): 525.614 Probability and Stochastic Processes for Engineers, 525.627 Digital Signal Processing, linear algebra, and familiarity with a scientific programming language such as MATLAB.

Instructor(s): Najmi

525.722 Wireless and Mobile Cellular Communications

In this course, students examine fundamental concepts of mobile cellular communications and specifics of current and proposed US 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; GSM, cdmaOne, GPRS, EDGE, cdma2000, W-CDMA, LTE and candidate 5G waveforms.

Prerequisite(s): 525.614 Probability and Stochastic Processes for Engineers or equivalent and 525.616 Communication Systems Engineering.

Instructor(s): Zuelsdorf

525.724 Introduction to Pattern Recognition

This course focuses on the underlying principles of pattern recognition and on the methods of machine intelligence used to develop and deploy pattern recognition applications in the real world. Emphasis is placed on the pattern recognition application development process, which includes problem identification, concept development, algorithm selection, system integration, and test and validation. Machine intelligence algorithms to be presented include feature extraction and selection, parametric and non-parametric pattern detection and classification, clustering, artificial neural networks, support vector machines, rule-based algorithms, fuzzy logic, genetic algorithms, and others. Case studies drawn from actual machine intelligence applications will be used to illustrate how methods such as pattern detection and classification, signal taxonomy, machine vision, anomaly detection, data mining, and data fusion are applied in realistic problem environments. Students will use the MATLAB programming language and the data from these case studies to build and test their own prototype solutions.

Prerequisite(s): 525.614 Probability and Stochastic Processes for Engineers or equivalent. A course in digital signal or image processing is recommended, such as 525.627 Digital Signal Processing, 525.619 Introduction to Digital Image and Video Processing, 525.643 Real-Time Computer Vision, or 525.746 Image Engineering.

Instructor(s): Baumgart

525.725 Power Electronics

This course is designed to provide students a solid foundation on the fundamentals and principles of power electronics. Analytical modeling and control techniques will be introduced in addition to practical design considerations for switching regulators. Topics include steady state analysis, large and small signal modeling, control loop design, input filter and magnetic design, along with switch realization and efficiency evaluation. Advanced topics such as soft switching and active power factor correction will also be introduced. Each topic will include an in-class modeling and simulation component, utilizing MATLAB/Simulink, to reinforce concepts and provide the student with a practical design tool for evaluating compliance with typical performance requirements.

Prerequisite(s): 525.624 Analog Electronic Circuit Design I or equivalent.

Instructor(s): Reichl

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(s): 525.614 Probability and Stochastic Processes for Engineers or equivalent.

Instructor(s): Banerjee, Marble

525.732 Advanced Analog Electronic Circuit Design

This course extends the fundamental concepts of practical electronic circuit design developed in the course 525.624 Analog Electronic Circuit Design, beginning with a review of the general feedback method. Students then examine a range of devices, including operational amplifiers, A/D and D/A converters, and comparators. Applications include active filters, sensor conditioning, nonlinear transfer functions, and analog computation. Students explore these topics through a series of assignments supplemented with breadboard-level experimentation. All required test equipment will be provided to the student.

Prerequisite(s): 525.624 Analog Electronic Circuit Design or permission of the instructor.

Instructor(s): Houser

525.733 Deep Vision

Recent technological advances coupled with increased data availability have opened the door for a wave of revolutionary research in the field of Deep Learning. In particular, Deep Neural Networks (DNNs) continue to improve on state-of-the-art performance in many standard computer vision tasks including image classification, segmentation, object recognition, object localization, and scene recognition. With an emphasis on computer vision, this course will explore deep learning methods and applications in depth as well as evaluation and testing methods. Topics discussed will include network architectures and design, training methods, and regularization strategies in the context of computer vision applications. Following a seminar format, students will be expected to read, understand, and present recent publications describing the current state-of-the-art deep learning methods. Additionally, team projects will give students an opportunity to apply deep learning methods to real world problems.

Prerequisite(s): Students should have taken courses in computer vision and machine learning/pattern recognition, have basic familiarity with OpenCV, Python and C++, as well as prior class instruction in neural networks.

Instructor(s): Burlina, Drenkow

525.735 MIMO Wireless Communications

This course presents the fundamental concepts and techniques of multiple-input multiple-output (MIMO) communications over wireless communication channels. MIMO communications, which involve the use of multiple antennas at the transmitter and receiver, employ the use of signal processing techniques to enhance the reliability and capacity of communication systems without increasing the required spectral bandwidth. MIMO techniques are currently used or planned in many commercial and military communications systems. Topics include the derivation and application of the theoretical MIMO communications capacity formula; channel fading and multipath propagation; the concepts of transmit and receive space diversity; space-time block coding, with a special emphasis on Alamouti coding; space-time trellis coding; spatial multiplexing; and fundamentals of OFDM modulation and its relation to MIMO communications. Examples and applications will be presented as well as related MATLAB homework assignments.

Prerequisite(s): 525.616 Communication Systems Engineering; 525.614 Probability and Stochastic Processes for Engineers, or the equivalent. In addition, a working knowledge of MATLAB is required.

Instructor(s): Hampton

525.738 Advanced Antenna Systems

This course is designed to follow 525.618 Antenna Systems. Advanced techniques needed to analyze antenna systems are studied in detail. Fourier transforms are reviewed and applied to antenna theory and array distributions. The method of moments is studied and used to solve basic integral equations employing different basis functions. Green's functions for patch antennas are formulated in terms of Sommerfeld-like integrals. Techniques such as saddle-point integration are presented. Topics addressed include computational electromagnetics, Leaky and surface waves, mutual coupling, and Floquet modes. Students should be familiar with complex variables (contour integration), Fourier transforms, and electromagnetics from undergraduate studies.

Prerequisite(s): 525.618 Antenna Systems.

Instructor(s): Weiss

525.742 System-on-a-Chip FPGA Design Laboratory

This lab-oriented course will focus on the design of large-scale system-on-a-chip (SOC) solutions within field-programmable gate arrays (FPGAs). Modern FPGA densities and commercially available cores enable a single developer to design highly complex systems within a single FPGA. This class will provide the student with the ability to design and debug these inherently complex systems. Topics will include high-speed digital signal processing, embedded processor architectures, customization of soft-core processors, interfacing with audio and video sensors, communications interfaces, and networking. The optimum division of algorithms between hardware and software will be discussed, particularly the ability to accelerate software algorithms by building custom hardware. Many labs will center on a common architecture that includes signal processing algorithms in the FPGA fabric, controlled by an embedded processor that provides user interfaces and network communication. The first section of the course will be spent experimenting with different building blocks for constructing SOCs. Students will spend later class sessions working in teams on self-directed SOC design projects. Industry-standard tools will be used.

Prerequisite(s): 525.642 FPGA Design Using VHDL and familiarity with C programming.

Instructor(s): Orr, Wenstrand

525.743 Embedded Systems Development Laboratory

This project-based laboratory course involves the development of embedded system prototypes. Typical projects contain combinations of the following component types: transducers, analog front ends, micro-controllers and processors, FPGAs, digital signal processors, electrical interfaces, wired or wireless connectivity, printed circuit boards required for integration and test, and software/firmware modules needed to operate a designed system. The laboratory activity is a backdrop used to teach key aspects of the development process such as documentation, realistic use of requirements, design partition, integration strategy, interface design, risk mitigation, and design strategies to accommodate available resources. Students will select a project concept and then create an implementation plan that will define the semester's activity. Students may work independently or in teams to define, develop, test, and document their projects. Students are encouraged to select topics based on their interests and learning objectives. All projects are subject to instructor approval.

Prerequisite(s): An undergraduate degree in electrical or computer engineering or computer science, 525.612 Computer Architecture, and working knowledge of C or C++ or instructor's approval.

Instructor(s): Houser

525.744 Passive Emitter Geo-Location

This course covers the algorithms used to locate a stationary RF signal source, such as a radar, radio, or cell phone. The topics covered include a review of vectors, matrices, and probability; linear estimation and Kalman filters; nonlinear estimation and extended Kalman filters; robust estimation; data association; measurement models for direction of arrival, time difference of arrival, and frequency difference of arrival; geo-location algorithms; and performance analysis. Most of the course material is developed in planar Cartesian coordinates for simplicity; however, the extension to WGS84 coordinates is provided to equip the students for practical applications. Homework consists of both analytical problems and problems that require computer simulation using software such as MATLAB.

Prerequisite(s): 525.614 Probability and Stochastic Processes for Engineers, an undergraduate course in linear algebra/matrix theory, and familiarity with MATLAB.

Instructor(s): Boggio, Samsundar

525.745 Applied Kalman Filtering VL

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(s): 525.614 Probability and Stochastic Processes for Engineers and 525.666 Linear System Theory or equivalents; knowledge of MATLAB (or equivalent software package).

Instructor(s): Samsundar, Watkins

525.746 Image Engineering

The overall goal of the course is to provide the student with a unified view of images, concentrating on image creation, and image processing. Optical, photographic, analog, and digital image systems are highlighted. Topics include image input, output, and processing devices; visual perception; video systems; and fundamentals of image enhancement and restoration. Coding, filtering, and transform techniques are covered, with applications to remote sensing and biomedical problems.

Prerequisite(s): 525.627 Digital Signal Processing or equivalent and knowledge of linear systems.

Instructor(s): Miller

525.747 Speech Processing

This course emphasizes processing of the human speech waveform, primarily using digital techniques. Theory of speech production and speech perception as related to signals in time and frequency-domains is covered, as well as the measurement of model parameters, short-time Fourier spectrum, and linear predictor coefficients. Speech coding, recognition, speech synthesis, and speaker identification are discussed. Application areas include telecommunications telephony, Internet VOIP, and man-machine interfaces. Considerations for embedded realization of the speech processing system will be covered as time permits. Several application-oriented software projects will be required.

Prerequisite(s): 525.627 Digital Signal Processing and 525.614 Probability and Stochastic Processes for Engineers. Background in linear algebra and MATLAB is helpful.

Instructor(s): Carmody

525.748 Synthetic Aperture Radar

This course covers the basics of synthetic aperture radar (SAR) from a signal processing perspective. In particular, the course will examine why there are limiting design considerations for real aperture radar and how a synthetic aperture can overcome these limitations to create high-resolution radar imaging. Various SAR geometries will be considered. Image formation algorithms, such as range Doppler, chirp scaling, omega-K, polar formatting, and backprojection, will be reviewed and, in some cases, coded by the student. Other post-processing techniques, such as motion compensation, aperture weighting (or apodization), autofocus, and multilook, will be reviewed. Advanced topics will include interferometric SAR, polarimetry, continuous wave linear FM (CWLFM) SAR, and moving objects in SAR imagery. Students will work through problems involving radar and SAR processing. Students will also develop SAR simulations, in either MATLAB or Python, based on simple point scatterers in a benign background.

Prerequisite(s): 525.648 Introduction to Radar Systems, along with either basic MATLAB or Python skills.

Instructor(s): Jansing

525.751 Software Radio for Wireless Communications

This course will explore modern software radio technology and implementation. Field-programmable gate arrays (FPGAs) have traditional uses in radar and other large digital signal processing systems. However, with recent advances, FPGAs are becoming key components in smaller software radios. We will explore concepts and techniques that are essential to implementing traditionally analog and ASIC signal processing functions in easily reconfigured digital logic. Students will design software radio functions and algorithms for FPGAs using rapid prototyping tools and techniques. A semester project involving demodulation and synchronization or other topics is required.

Prerequisite(s): 525.638 Introduction to Wireless Technology or 525.616 Communication Systems Engineering; 525.627 Digital Signal Processing; and working knowledge of MATLAB and Simulink.

Instructor(s): Chew

525.752 Digital Receiver Synchronization Techniques VL

This course explores synchronization techniques in modern digital receivers. Synchronization techniques, from initial detection of a signal to symbol timing recovery, is studied in this course. Students will learn practical synchronization techniques through experimentation and hands-on development. Students develop software to solve synchronization problems relevant to modern wireless communication standards. A semester project involving demodulation and synchronization is required.

Prerequisite(s): 525.627 Digital Signal Processing

Instructor(s): Chew

525.753 Laser Systems and Applications

This course provides a comprehensive treatment of the generation of laser light, and its properties and applications. Topics include specific laser systems and pumping mechanisms, nonlinear optics, temporal and spatial coherence, guided beams, interferometric and holographic measurements, and remote sensing.

Prerequisite(s): 525.625 Laser Fundamentals.

Instructor(s): A. Brown, D. Brown, Thomas

525.754 Wireless Communication Circuits

In this course, students examine modulator and demodulator circuits used in communication and radar systems. A combination of two lectures, three laboratory experiments, and a student design project address the analysis, design, fabrication, and test of common circuits. Signal formats considered include phase and frequency shift keying, as well as the linear modulations used in analog systems. The students will select a project topic of their choosing. The nature and extent of the project will be negotiated with the instructors. The project will consume about two-thirds of the semester and weighs in a similar proportion for the final grade. There are no exams in this course, it is a laboratory and project-based learning experience.

Prerequisite(s): 525.616 Communication Systems Engineering or 525.624 Analog Electronic Circuit Design or 525.654 Communications Circuits Laboratory or permission of the instructor.

Instructor(s): Kaul, Tobin, A. Wilson

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.

Prerequisite(s): Undergraduate courses on electromagnetic theory and elementary quantum mechanics. A course on Fourier optics is helpful.

Instructor(s): Thomas

525.759 Image Compression, Packet Video, and Video Processing

This course provides an introduction to the basic concepts and techniques used for the compression of digital images and video. Video compression requirements, algorithm components, and ISO Standard video processing algorithms are studied. Image compression components that are used in video compression methods are also identified. Since image and video compression is now integrated in many commercial and experimental video processing methods, knowledge of the compression methods' effects on image and video quality are factors driving the usability of that data in many data exploitation activities. Topics to be covered include introduction to video systems, Fourier analysis of video signals, properties of the human visual system, motion estimation, basic video compression techniques, videocommunication standards, and error control in video communications. Video processing applications that rely on compression algorithms are also studied. A mini-project is required.

Prerequisite(s): 525.627 Digital Signal Processing.

Instructor(s): Beser

525.761 Wireless and Wireline Network Integration

This course investigates the integration of wireless and wireline networks into seamless networks. The current telecommunications environment in the United States is first discussed, including the state of technology and regulations as they apply to the wireless and wireline hybrid environment. Then each type of these hybrid networks is discussed, including its components, network services, architecture, and possible evolution, as well as important concepts that support the evolution of networks. The integration of wired network advance intelligence, wireless network mobility, and long distance capabilities are shown to provide many new combinations of wired and wireless services to users.

Prerequisite(s): 525.608 Next-Generation Telecommunications or 525.616 Communication Systems Engineering, or permission of instructor.

Instructor(s): R. Lee

525.762 Signal Processing with Wavelets

This course covers the mathematical framework for wavelets, with particular emphasis on algorithms and implementation of the algorithms. Concepts of frames, orthogonal bases, and reproducing kernel Hilbert spaces are introduced first, followed by an introduction to linear systems for continuous time and discrete time. Next, time, frequency, and scale localizing transforms are introduced, including the windowed Fourier transform and the continuous wavelet transform (CWT). Discretized CWT is studied next in the forms of the Haar and the Shannon orthogonal wavelet systems. General multi-resolution analysis is introduced, and the time domain and frequency domain properties of orthogonal wavelet systems are studied with examples of compact support wavelets. The discrete wavelet transform (DWT) is introduced and implemented. Biorthogonal wavelet systems are also described. Orthogonal wavelet packets are discussed and implemented. Wavelet regularity and the Daubechies construction is presented next. Finally the 2D DWT is discussed and implemented. Applications of wavelet analysis to de-noising and image compression are discussed together with an introduction to image coding.

Prerequisite(s): 525.627 Digital Signal Processing and the basics of linear systems.

Instructor(s): Najmi

525.768 Wireless Networks

This is a hands-on course that integrates teaching of concepts in wireless LANs as well as offering students, in an integrated lab environment, the ability to conduct laboratory experiments and design projects that cover a broad spectrum of issues in wireless LANs. The course will describe the characteristics and operation of contemporary wireless network technologies such as the IEEE 802.11 and 802.11s wireless LANs and Bluetooth wireless PANs. Laboratory experiments and design projects include MANET routing protocols, infrastructure and MANET security, deploying hotspots, and intelligent wireless LANs. The course will also introduce tools and techniques to monitor, measure, and characterize the performance of wireless LANs as well as the use of network simulation tools to model and evaluate the performance of MANETs.

Prerequisite(s): 525.641 Computer and Data Communication Networks or 605.671 Principles of Data Communications Networks.

Instructor(s): Refaei

525.770 Intelligent Algorithms

Intelligent algorithms are, in many cases, practical alternative techniques for tackling and solving a variety of challenging engineering problems. For example, fuzzy control techniques can be used to construct nonlinear controllers via the use of heuristic information when information on the physical system is limited. Such heuristic information may come, for instance, from an operator who has acted as a "human-in-the-loop" controller for the process. This course investigates a number of concepts and techniques commonly referred to as intelligent algorithms; discusses the underlying theory of these methodologies when appropriate; and takes an engineering perspective and approach to the design, analysis, evaluation, and implementation of intelligent systems. Fuzzy systems, genetic algorithms, particle swarm and ant colony optimization techniques, and neural networks are the primary concepts discussed in this course, and several engineering applications are presented along the way. Expert (rule-based) systems are also discussed within the context of fuzzy systems. An intelligent algorithms research paper must be selected from the existing literature, implemented by the student, and presented as a final project.

Prerequisite(s): Student familiarity of system-theoretic concepts is desirable.

Instructor(s): Palumbo

525.771 Propagation of Radio Waves in the Atmosphere

This course examines various propagation phenomena that influence transmission of radio frequency signals between two locations on earth and between satellite-earth terminals, with a focus on applications. Frequencies above 30 MHz are considered with emphasis on microwave and millimeter propagation. Topics include free space transmission, propagation, and reception; effects on waves traversing the ionosphere; and attenuation due to atmospheric gases, rain, and clouds. Brightness temperature concepts are discussed, and thermal noise introduced into the receiver system from receiver hardware and from atmospheric contributions are examined. Also described are reflection and diffraction effects by land terrain and ocean, multipath propagation, tropospheric refraction, propagation via surface and elevated ducts, scatter from fluctuations of the refractive index, and scattering due to rain. Atmospheric dynamics that contribute to the various types of propagation conditions in the troposphere are described.

Prerequisite(s): An undergraduate degree in electrical engineering or equivalent.

Instructor(s): Dockery

525.772 Fiber-Optic Communication Systems

This course investigates the basic aspects of fiber-optic communication systems. Topics include sources and receivers, optical fibers and their propagation characteristics, and optical fiber systems. The principles of operation and properties of optoelectronic components, as well as the signal guiding characteristics of glass fibers, are discussed. System design issues include terrestrial and submerged point-to-point optical links and fiber-optic networks.

Prerequisite(s): 525.691 Fundamentals of Photonics.

Instructor(s): Sova

525.774 RF and Microwave Circuits I

In this course, students examine RF and microwave circuits appropriate for wireless communications and radar sensing. The course emphasizes the theoretical and experimental aspects of micro-strip design of highly integrated systems. 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(s): 525.623 Principles of Microwave Circuits or 525.620 Electromagnetic Transmission Systems.

Instructor(s): 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(s): 525.774 RF and Microwave Circuits I.

Instructor(s): Penn, Thompson

525.776 Information Theory

Information theory concerns the fundamental limits for data compressibility and the rate at which data may be reliably communicated over a noisy channel. Course topics include measures of information, entropy, mutual information, Markov chains, source coding theorem, data compression, noisy channel coding theorem, error-correcting codes, and bounds on the performance of communication systems. Classroom discussion and homework assignments will emphasize fundamental concepts, and advanced topics and practical applications (e.g., industry standards, gambling/finance, machine learning) will be explored in group and individual research projects.

Prerequisite(s): 525.614 Probability and Stochastic Processes for Engineers or equivalent.

Instructor(s): Ratto

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.

Prerequisite(s): 525.666 Linear System Theory and 525.609 Continuous Control Systems or the equivalent.

Instructor(s): 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 trade-offs between redundancy, testability, complexity, and fault tolerance are explored. Although the emphasis is predominantly on electronics, related examples from the aerospace and software industries are included. The concepts of fault lists, collapsed fault lists, and other techniques for reducing the complexity of fault simulation are addressed. A quantitative relationship between information theory, error correction codes, and reliability is developed. Finally, the elements of a practical quality assurance system are presented. In addition to homework assignments, students will conduct an in-depth, quantitative case study of a practical system of personal interest.

Prerequisite(s): 525.614 Probability and Stochastic Processes or equivalent.

Instructor(s): 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 semiconductor fabrication, device models, and RF/microwave design techniques using a typical SiGe process. Part of the course will involve student design projects using a CAD software to design amplifiers, mixers, etc.

Prerequisite(s): 525.774 RF and Microwave Circuits I or equivalent.

Instructor(s): Penn, J. Wilson

525.780 Multidimensional Digital Signal Processing VL

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.

Prerequisite(s): 525.614 Probability and Stochastic Processes for Engineers and 525.627 Digital Signal Processing or equivalents. Knowledge of linear algebra and MATLAB is helpful.

Instructor(s): Newsome

525.783 Spread-Spectrum Communications

This course presents an analysis of the performance and design of spread-spectrum communication systems. Both direct-sequence and frequency-hopping systems are studied. Topics include pseudonoise sequences, code synchronization, interference suppression, and the application of error-correcting codes. The use of code-division multiple access in digital cellular systems is examined. The relationships between spread spectrum, cryptographic, and error correction systems are explored. The mathematics of pseudo-random sequences used as spreading codes is compared with the mathematics of complex numbers with which students are already familiar.

Prerequisite(s): 525.616 Communication Systems Engineering. Students should have knowledge of material covered in 525.201 Circuits, Devices, and Fields and 525.202 Signals and Systems.

Instructor(s): Jablonski

525.786 Human-Robotics Interaction

This course provides an investigation of human-robot interaction and prosthetic control, with a focus on advanced man-machine interfaces including neural signal processing, electromyography, and motion tracking interfaces for controlling and receiving feedback from robotic devices. The course will also cover human physiology and anatomy, signal processing, intent determination, communications between the human and the device, haptic feedback, and telepresence. It is designed to be a hands-on course with class time spent in the dedicated robotics lab designing interfaces and performing experiments in a Virtual Integration Environment (VIE) and with robotic devices. Additional time in the lab, outside of class time, may be required to complete the course project. Programming for the class will be in MATLAB and Simulink.

Prerequisite(s): 525.627 Digital Signal Processing, knowledge of linear algebra, and familiarity with MATLAB and Simulink.

Instructor(s): Armiger, Lesho

525.787 Microwave Monolithic Integrated Circuit (MMIC) Design

This course is for advanced students who have a background in microwave circuit analysis and design techniques and are familiar with modern microwave computer-aided engineering tools. The course covers the monolithic implementation of microwave circuits on GaAs, or other III/V, 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 design that would be ready for submission to a foundry for fabrication.

Prerequisite(s): 525.775 RF and Microwave Circuits II.

Instructor(s): Penn

525.788 Power Microwave Monolithic Integrated Circuit (MMIC) Design

This course covers additional circuit design techniques applicable to MMICs (and microwave circuits in general). It is an extension of 525.774/775 RF and Microwave Circuits I and II and 525.787 Microwave Monolithic Integrated Circuit (MMIC) Design, although for students with a microwave background, these particular courses are not prerequisites. The topics covered include broadband matching, optimum loads for efficiency and low intermodulation products, odd mode oscillations, details of nonlinear modeling, time domain simulation of nonlinear circuits, and thermal effects. Students do need to have a background in microwave measurements and microwave CAD tools. No project is required, but there is structured homework involving power MMIC design completed by the student using a foundry library.

Instructor(s): Dawson

525.789 Advanced Satellite Communications

This course covers advanced topics in satellite communications systems, including investigations of electromagnetics, quantum physics, relativity, orbital mechanics, information theory, and hardware design relevant to practical system design and analysis. Satellite and ground station antennae, including wire, helical, and loop antennae, parabolic dishes, and multiple spot beam phased arrays, are considered from first principles. Electromagnetic wave propagation models that include reflection, polarization, diffraction, refraction, and ionospheric effects are studied as functions of frequency, including at millimeter and x-ray wavelengths. Modulation, coding, multiplexing, channel capacity, filtering, noise, and error correction, for both analog and digital systems, are treated, enabling accurate analyses at higher frequencies for which convention models may fail. The effects of special and general relativity on Doppler shifts and on-orbit clock errors are introduced. Kepler's laws are derived from first principles and used to build a simple, spreadsheet-based orbital mechanics propagator to model link budget and mission designs from low earth orbit to interplanetary space. Using GPS as a case study, it is shown how each of the above topics plays a critical role in the overall design of a complete satellite system. Course materials are augmented by in-class demonstrations, including component level designs to real-time observation of GPS and geostationary satellites using a portable satcom antenna.

Prerequisite(s): 525.616 Communication Systems Engineering and 525.640 Satellite Communications Systems. Students should have knowledge of material covered in 525.201 Circuits, Devices, and Fields and 525.202 Signals and Systems.

Instructor(s): Jablonski

525.790 RF Power Amplifier Design Techniques

This course addresses foundational power amplifier circuit concepts and engineering fundamentals. The design of high power/high efficiency amplifiers that satisfy specific system requirements (bandwidth, linearity, spectral mask, etc.) are covered. Various device technologies (GaAs, GaN, LDMOS, SiGe), device scaling and modeling, optimum load calculations, amplifier classes (A, B, AB, C, E, F, etc.), waveform engineering, modulation techniques, efficiency enhancement, odd/even mode stability analysis, linearization techniques, power combining, reliability, lifetime calculation, and packaging are studied. The concepts are explored theoretically, and practically using numerous design exercises. This course stresses hands-on design techniques and practical considerations for real-world situations and applications.

Prerequisite(s): 525.623 Principles of Microwave Circuits or 525.620 Electromagnetic Transmission Systems.

Instructor(s): Darwish

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(s): 525.774 RF and Microwave Circuits I.

Instructor(s): Everett, Fazi

525.793 Advanced Communication Systems

This course provides a basic introduction to the various building blocks of a modern digital communications system, focusing on the physical layer (PHY). We will first review basic concepts in digital communications, including Shannon theory, Nyquist sampling theory, optimal detection under Gaussian white noise, and basic modulations. We will then treat several building blocks of a digital receiver, including time and frequency synchronization, adaptive equalization and precoding, and error-correction coding/decoding. We will also introduce some advanced communication technologies such as Orthogonal Frequency-Division Multiplexing (OFDM) and Multiple-Input Multiple-Output (MIMO). Finally we will apply the knowledge to some practical wireless and wired systems.

Prerequisite(s): 525.614 Probability and Stochastic Processes for Engineers; 525.616 Communication Systems Engineering.

Instructor(s): Ouyang

525.796 Introduction to High-Speed Optoelectronics

This course provides the student with the fundamental concepts needed to address issues in both the design and test of high-speed optoelectronic systems. This is an emerging field where photonics is combined with high-speed electronics to generate, transmit, and process signals from microwave to terahertz frequencies. The purpose of this course is to introduce fundamental principles and state-of-the-art system applications. Topics include photonic and high-speed electronic principles, analog fiber optic link, principles of low-phase noise microwave sources, photonic methods for generating low-phase noise microwave signals, photonic-based RF signal processing techniques, and ultra-short optical pulse generation techniques. State-of-the-art applications include the low-phase noise opto-electronic oscillator, carrier envelope phase locked laser for time and frequency standards, photonic-based complex radar signal generators, phased-array antenna architectures including true time-delay beam forming and the ALMA radio-telescope array, photonic analog-to-digital converter techniques, electro-optic sampling, and Terahertz signal generation.

Prerequisite(s): Bachelor's degree in electrical engineering or physics. An undergraduate course in electromagnetics is required. A course in microwave theory is preferred.

Instructor(s): Sova

525.797 Advanced Fiber Optic Laboratory

The purpose of this laboratory course is to expose students to state-of-the-art applications of fiber optic technologies that include continuous-wave (cw) and pulsed fiber lasers, high-speed digital fiber optic communication systems, microwave photonic links, and non-linear fiber optic signal processing and sensors. The first part of the course will focus on a thorough characterization of fiber laser systems starting with the erbium-doped fiber amplifier and implementing different laser configurations that include multi-mode cw operation, Q-switching and relaxation oscillations, non-linear based mode-locking and single longitudinal mode operation. All of the measurements will be compared to theoretical models. This will provide students with hands-on experience with concepts that are applicable to all laser systems. In the latter part of the course, students will select a few topics that demonstrate both modern fiber optic systems based on cw lasers, external electro-optic modulators and high-speed photodetectors and applications of nonlinear fiber optics using self-phase modulation, stimulated Brillouin scattering, stimulated Raman scattering, and four wave mixing. These topics highlight the breadth of applications of modern fiber optic systems. Again, all of the experiments will be compared to theoretical models.

Prerequisite(s): 525.691 Fundamentals of Photonics or 615.751 Modern Optics or equivalent.
Instructor(s): Sova

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. Students should be in the second half of their graduate studies. Further information is available from the program chair. Such arrangements are made relatively infrequently. This course number should be used for the first registration of a student in any special project.
Course Note(s): To ensure consideration for any term, project proposals should reach the program chair by the end of the registration period.
Instructor(s): Faculty

525.802 Special Project II
This course number should be used for the second registration of a student in any special project. (See course 525.801 Special Project I for a further description.)
Course Note(s): To ensure consideration for any term, project proposals should reach the program chair by the end of the registration period.
Instructor(s): Faculty

525.803 Electrical and Computer Engineering Thesis
First of two-course sequence designed for students in the electrical and computer engineering graduate program who wish to undertake a thesis project after completing all other requirements for their degree. Students work with an advisor to conduct independent research and development in Electrical and Computer Engineering (ECE) leading to a written thesis and oral presentation to a thesis committee. The intent of the research may be to advance the body of knowledge in one of the technology areas in the ECE program.
Prerequisite(s): Completion of all other courses applicable to the ECE graduate degree and approval of the ECE program chair and vice chair. The thesis option is appropriate for highly motivated students with strong academic records.
Instructor(s): Faculty

525.804 Electrical and Computer Engineering Thesis
Second of two-course sequence designed for students in the electrical and computer engineering graduate program who wish to undertake a thesis project after completing all other requirements for their degree. Students work with an advisor to conduct independent research and development in Electrical and Computer Engineering (ECE) leading to a written thesis and oral presentation to a thesis committee. The intent of the research may be to advance the body of knowledge in one of the technology areas in the ECE program.
Prerequisite(s): Completion of all other courses applicable to the ECE graduate degree and approval of the ECE program chair and vice chair. The thesis option is appropriate for highly motivated students with strong academic records.
Instructor(s): Faculty

MECHANICAL ENGINEERING

535.606 Advanced Strength of Materials
This course reviews stress and strain in three dimensions, elastic and inelastic material behavior, and energy methods. It also covers use of the strength of materials approach to solving advanced problems of torsion and bending of beams.
Prerequisite(s): Fundamental understanding of stress and strain and axial, torsion, and bending effects in linear elastic solids.
Instructor(s): Burkhardt

535.609 Topics in Data Analysis
This course will provide a survey of standard techniques for the extraction of information from data generated experimentally and computationally. The approach will emphasize the theoretical foundation for each topic followed by applications of each technique to sample experimental data. The student will be provided with implementations to gain experience with each tool to allow the student to then quickly adapt to other implementations found in common data analysis packages. Topics include uncertainty analysis, data fitting, feed-forward neural networks, probability density functions, correlation functions, Fourier analysis and FFT procedures, spectral analysis, digital filtering, and Hilbert transforms.
Prerequisite(s): Projects will require some programming experience or familiarity with tools such as MATLAB.
Instructor(s): Hess

535.610 Computational Methods of Analysis
This course serves as an introduction to using MATLAB for typical engineering analyses and may serve as a valuable precursor to the more computationally intensive courses in the program that use MATLAB. Course topics include an introduction to script programming, solution of one- and two-dimensional definite integrals, solution of coupled sets of ordinary differential equations, typical data analysis (e.g., Fourier transforms, curve fitting, and signal processing), and matrix manipulation (e.g., solution of linear systems and eigenvalue extraction).
Instructor(s): Burkhardt

535.612 Intermediate Dynamics

This course develops student's ability to accurately model the dynamics of single and multi-body engineering systems undergoing motion in 3D space. The course begins with formulating the differential geometry and kinematics of curvilinear coordinates to permit kinematic descriptions of relative motion and rotation of rigid bodies and mechanisms subject to common engineering constraints such as substructure interconnections, dry friction, and rolling. Momentum and inertia properties of rigid body dynamics follow. Students are then introduced to analytical dynamics, where Lagrange's equations and Kane's method are derived and studied to facilitate efficient formulation of the equations of motion governing the dynamics of systems subject to conservative and non-conservative forces and engineering constraints. The course also concludes with gyroscopic dynamics with applications to inertial guidance and spacecraft attitude dynamics.

Prerequisite(s): Mathematics through calculus and linear algebra.

Instructor(s): Stanton

535.613 Structural Dynamics and Stability

This course introduces the propagation of elastic waves, and the loss of stability in engineering structures and systems. In the first part of the course, fundamental physical principles of elasticity and wave mechanics are reviewed and developed to provide students with the capability to model and analyze wave propagation, reflection, and refraction in isotropic and anisotropic engineering structures such as rods, beams, and plates. In the second part of the course, mechanical stability models are studied and applied in terms of dynamic behavior where the combined effects of vibration, gyroscopic motion, impact/shock, and buckling lead to new structural configurations or unstable motions that must often be avoided in design. Applications span nondestructive evaluation, composites, cables, aircraft/space structures, rotordynamics, aeroelasticity, civil engineering structures, and others.

Prerequisite(s): Undergraduate or graduate course in vibrations.

Instructor(s): Stanton

535.614 Fundamentals of Acoustics

This course provides an introduction to the physical principles of acoustics and their application. Fundamental topics include the generation, transmission, and reception of acoustic waves. Applications covered are selected from underwater acoustics, architectural acoustics, remote sensing, and nondestructive testing.

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

Instructor(s): Burkhardt

535.621 Intermediate Fluid Dynamics

This course prepares the student to solve practical engineering flow problems and concentrates on the kinematics and dynamics of viscous fluid flows. Topics include the control volume and differential formulations of the conservation laws, including the Navier-Stokes equations. Students examine vorticity and circulation, dynamic similarity, and laminar and turbulent flows. The student is exposed to analytical techniques and experimental methods, and the course includes an introduction to computational methods in fluid dynamics. It also includes a programming project to develop a numerical solution to a practical fluid flow problem.

Prerequisite(s): An undergraduate fluid mechanics course.

Instructor(s): Hess

535.622 Robot Motion Planning

This course investigates the motion planning problem in robotics. Topics include motion of rigid objects by the configurations space and retraction approaches, shortest path motion, motion of linked robot arms, compliant motion, coordinated motion of several objects, robust motion with error detection and recovery, and motion in an unknown environment.

Instructor(s): Kim, Kutzer

535.623 Intermediate Vibrations

Course topics include transient and forced vibration of 1- 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(s): An undergraduate vibrations course.

Instructor(s): Stanton

535.627 Computer-Aided Design

This course provides a wide-ranging exploration of computer-aided design (CAD) using Creo Parametric (a PTC CAD software, previously called Pro/ENGINEER). Topics include sketching, solid modeling, assembly modeling, detail drafting, geometric dimensioning and tolerancing, advanced modeling, sheet metal modeling, mechanism dynamics, and structural/thermal finite element analysis (FEA).

Instructor(s): Boyle

535.628 Computer-Integrated Design and Manufacturing

This course emphasizes the computer automation of design and manufacturing systems. A survey of the automation techniques used for integration in modern design and manufacturing facilities is presented. Discussions are presented related to the system integration of computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM), robotics, material resource planning, tool management, information management, process control, and quality control. The current capabilities, applications, limitations, trends, and economic considerations are stressed.

Instructor(s): Ivester

535.629 Energy Engineering

The course will focus on an analytical system performance technique known as Availability or Exergy Analysis, which is based on the second law of thermodynamics. The course focuses on traditional power and refrigeration systems. However, nontraditional power generation systems will be considered by way of a special project of each student's choice. It will include an engineering description of the state of the art of the selected topic (e.g., wind or solar power, fuel cell, etc.), and a second law performance analysis of a prototype system will be presented to the class. In addition to the power system topics, the availability analysis will be applied to the combustion and psychrometric processes.

Instructor(s): Faculty

535.630 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.

Prerequisite(s): The course project and assignments will require some programming experience or familiarity with tools such as MATLAB.

Instructor(s): Armand

535.631 Introduction to Finite Element Methods

Topics covered by this course include theory and implementation of finite element models for typical linear problems in continuum mechanics including fluid flow, heat transfer, and solid mechanics. Emphasis will be placed on developing a fundamental understanding of the method and its application.

Course Note(s): Cannot be counted with 560.730 Finite Element Methods from the full-time Civil Engineering Department.

535.632 Applied Finite Elements

This course provides an introduction to the study of mechanics using the finite element method. Topics include the stiffness method, stationary principles, the Rayleigh-Ritz method, displacement-based elements, isoparametric formulation, and coordinate transformation. A general purpose finite element analysis package will be used for computer project assignments. Students who successfully complete this course will be able to utilize general purpose commercial code to solve linear two- and three-dimensional problems in statics and vibrations.

535.633 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(s): An undergraduate heat transfer course.

Instructor(s): Green

535.634 Applied Heat Transfer

This course focuses on the inevitable tradeoffs associated with any thermodynamic or heat transfer system, which result in a clear distinction between workable and optimal systems. The point is illustrated by means of a number of concrete problems arising in power and refrigeration systems, electronics cooling, distillations columns, heat exchange, and co-generation systems.

Prerequisite(s): An undergraduate heat transfer course.

Instructor(s): Kedzierski

535.635 Introduction to Mechatronics

Mechatronics is the integration of mechanisms, electronics, and control. This interdisciplinary course is primarily lab and project based, but also includes lectures to provide background in key underlying principles. The course's main objective is to provide experience designing and prototyping a mechatronic or robotic system to accomplish a specific task or challenge. Topics include mechanism design, motor and sensor integration and theory, programming of microprocessors, mechanics prototyping, and the design process. Students will work in teams to complete a hardware-based final project.

Prerequisite(s): Mathematics through calculus and linear algebra.

Instructor(s): Wolfe

535.641 Mathematical Methods for Engineers

This course covers a broad spectrum of mathematical techniques needed to solve advanced problems in engineering. Topics include linear algebra, the Laplace transform, ordinary differential equations, special functions, partial differential equations, and complex variables. Application of these topics to the solutions of physics and engineering problems is stressed.

Prerequisite(s): Vector analysis and ordinary differential equations.

Instructor(s): Nakos

535.642 Control Systems for Mechanical Engineering Applications

This class provides a comprehensive introduction to the theory and application of classical control techniques for the design and analysis of continuous-time control systems for mechanical engineering applications. Topics include development of dynamic models for mechanical, electrical, fluid-flow and process-control systems, introduction to Laplace transforms, stability analysis, time and frequency domain analysis techniques, and classical design methods. The class will use a series of applications that build in complexity throughout the semester to emphasize and reinforce the material.

Instructor(s): Urban

535.645 Digital Control and Systems Applications

This class will provide a comprehensive treatment of the analysis and design of discrete-time control systems. The course will build upon the student's knowledge of classical control theory and extend that knowledge to the discrete-time domain. This course is highly relevant to aspiring control systems and robotics engineers since most control system designs are implemented in micro-processors(hence the discrete-time domain) vice analog circuitry. Additionally, the course will go into advanced control system designs in the state-space domain and will include discussions of modern control design techniques including linear-quadratic optimal control design, pole-placement design, and state-space observer design. The class will use a series of applications that build in complexity throughout the semester to emphasize and reinforce the material.

Prerequisite(s): 535.642 Control Systems for Mechanical Engineering Applications.

Instructor(s): Urban

535.650 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.

Prerequisite(s): Undergraduate-level exposure to thermodynamics, fluid dynamics, differential equations, and basic chemistry.

Instructor(s): Kweon

535.652 Thermal Systems Design and Analysis

Thermodynamics, fluid mechanics, and heat transfer principles are applied using a systems perspective to enable students to analyze and understand how interactions between components of piping, power, refrigeration, and thermal management systems affect the performance of the entire system. Following an overview of the fundamental principles involved in thermal and systems analyses, the course will cover mathematical methods needed to analyze the systems and will then explore optimization approaches that can be used to improve designs and operations of the thermal systems to minimize, for example, energy consumption or operating costs.

Prerequisite(s): Undergraduate courses in thermodynamics and heat transfer. No computer programming is required.

Instructor(s): Healy

535.654 Theory and Applications of Structural Analysis

This is a course in classical plate and shell structures with an emphasis on both analysis and application. Both differential and energy method approaches are presented. Topics include an introduction to thin plate theory, its application to circular and rectangular plates, buckling, and thermal effects. Classical thin shell theory is also presented. Applications to common plate and shell structures are discussed throughout.

Instructor(s): Burkhardt

535.659 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 how components are manufactured within high-tech industries are presented.

Instructor(s): Ivester

535.660 Precision Mechanical Design

This course will provide the student with a fundamental understanding of the principles and techniques used to design precision machines, instruments, and mechanisms. Lectures will include discussions on the implementation and design of mechanisms, bearings, actuators, sensors, structures, and precision mounts used in precision design. Upon completion of this course, students will have a clear understanding of positional repeatability and accuracy, deterministic design, exact constraint design, error modeling, and sources of machine and instrumentation errors.

Instructor(s): Fesperman

535.662 Energy and the Environment

The course focuses on advanced topics related to energy and thermodynamics. The objective of this course is to provide a thorough understanding of the environmental impacts related to energy conversion systems. The use of the second law of thermodynamics is introduced to quantify the performance of energy conversion systems. Topics such as global warming, alternative energy sources (solar, wind power, geothermal, tides, etc.), new technologies (fuel cells and hydrogen economy), and resources and sustainable development are addressed. A section of the course is devoted to current trends in nuclear energy generation and associated environmental issues

Prerequisite(s): Undergraduate-level exposure to thermodynamics.

Instructor(s): Herman

535.672 Advanced Manufacturing Systems

This course examines the effect that new technology, engineering, and business strategies have on transforming US industry into a world-class, competitive force. 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 illustrate how industry is adopting the latest technology to meet customer requirements for quality, low cost, and flexibility.

Instructor(s): Ivester

535.673 Mechanized Assembly: Hardware and Algorithms VL

Generally speaking, manufacturing engineering consists of two large subtopics: fabrication and assembly. This course covers topics in the design and analysis of mechanized assembly systems such as those used in parts feeding and pick-and-place machines. Specific topics will include: Describing Planar and Spatial Rotations, Planar Linkages (4-Bar, Crank-sliders), Classical Theory of Gears, Differential Geometry Methods, Singularities of Mechanisms and Robots, Spatial Linkage Synthesis and Screw Theory, Transmissions and Spatial Gearing, Automated Parts Transfer (Fences and Bowl Feeders), Assembly Planning, Tolerancing, Parts Entropy, Deployable Mechanism Design.

535.675 Thermal Sciences for the Built Environment

This course will explore the energy transfer in building applications through study of fundamental heat and mass transfer, principles of vapor compression systems, and simulation of energy flows using publicly available software. Buildings account for 40% of energy consumption in the United States, so application of the principles of mechanical engineering can greatly lessen the environmental impact of the built environment while providing the comfort expected from occupants. This course will study the interplay between energy and issues such as comfort, durability, and indoor air quality.

Instructor(s): Healy

535.684 Modern Polymeric Materials

This course will cover a broad range of topics in the polymeric materials science and engineering field. We will address the structure and property relationships in thermoplastics, thermoset, amorphous, semicrystalline, oriented and biological polymeric materials; synthesis and processing (including rheology) of polymers; flow and fracture of polymeric materials under different conditions. Modern polymer characterization techniques will be introduced. Frontiers in the recent findings in biopolymers, polymer based 3D printing, polymers for tissue engineering will also be discussed.

Instructor(s): Xia

535.691 Mechanics of Molecules and Cells

Biological macromolecules such as proteins and nucleic acids consist of thousands of atoms. Whereas crystallographic data of these molecules provide baseline information on their three-dimensional structure, their biological function can depend to a great extent on mechanical characteristics such as conformational flexibility. In this course, we will examine numerical methods for modeling shape fluctuations in large biomolecules using coarse-grained elastic network models based on foundations of engineering structural dynamics. The course will consist of attending lectures, reading papers, and performing computer projects. No prior knowledge of biochemistry or molecular biology is required.

Prerequisite(s): Knowledge of linear algebra and differential equations. Basic knowledge of Newtonian and Lagrangian dynamics will be helpful, but these will be reviewed.

535.711 Symmetries of Crystalline Solids VL

This course covers the mathematical techniques necessary for understanding of symmetry of the solid state topics such as lattices, crystals structure and X-ray diffraction experiment. The class uses examples from crystalline solids and crystallography to introduce mathematical concepts and related problem solving skills. Topics include linear algebra and eigenvalues and eigenvectors, tensor operations, symmetry operations, introduction to Fourier analysis, group theory, and crystallographic groups.

Instructor(s): Ghaani Farashahi

535.712 Applied Fluid Dynamics

This course will provide a survey of topics in applied fluid dynamics for the practicing engineer. The first topic will concentrate on pipe and duct flow, looking at friction factors, abrupt changes in area, and pipe systems. This is followed by unsteady flows focusing on pressure transients, such as the water hammer. A section on lubrication theory covering wedge and journal bearings is presented. Open channel flows are discussed with emphasis on optimum cross-sectional shape and specific energy. Turbomachinery such as axial and centrifugal pumps, including specific speed and suction limitations, is described. Fluid dynamic drag and lift from streamlined surfaces are presented, including topics such as vortex shedding, terminal velocity, and cavitation. The approach will emphasize the practical foundation needed to solve real-world problems.

Prerequisite(s): 535.621 Intermediate Fluid Dynamics. Projects will require some programming experience or familiarity with tools such as MATLAB.

Instructor(s): Hess

535.720 Analysis and Design of Composite Structures

Topics in this course include anisotropic elasticity, laminate analysis, strength of laminates, failure theories, bending, buckling, and vibration of composite plates. The second part of the course is devoted to the applications of the structural analysis of composite structures by means of finite-elements computer codes.

535.724 Dynamics of Robots and Spacecraft

This course provides an introduction to Lagrangian mechanics with application to robot and spacecraft dynamics and control. Topics include rigid body kinematics, efficient formulation of equations of motion by using Lagrange's equations, solutions of equations of motion, Hamilton's principle, and introduction to stability and control theory.

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.

Prerequisite(s): 535.630 Kinematics and Dynamics of Robots, ordinary differential equations, linear algebra.

Instructor(s): Armand

535.727 Advanced Machine Design

This course provides a broad treatment of stress, strain, and strength with reference to engineering design and analysis. Major emphasis is placed on the analytical and experimental methods of determination of stresses in relationship to the strength properties of machine elements under various loading conditions. Also considered are deflection, post-yield behavior, residual stresses, thermal stresses, creep, and extreme temperature effects as applied to the design of fasteners, shafts, power trains, and rotational machinery.

Instructor(s): Fesperman

535.731 Engineering Materials: Properties and Selection

Become familiar with different classes of engineering materials and their tradeoffs associated with design criteria such as strength, toughness, corrosion resistance, and fabricability, as well as some common test methods for evaluating material properties. This course will concentrate on metal alloys but will also consider polymers and ceramics. Topics specific to metals will include effects of work hardening and heat treatment, corrosion, and elevated temperature properties. Topics specific to polymers will include viscoelasticity, stress relaxation and creep, and phase transitions. Topics specific to ceramics will include flaw-dominated strength, fracture energy, and statistical determination of strength. The course also includes an introduction to the Ashby method of material selection and optimization.

Instructor(s): Lennon

535.736 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.

Prerequisite(s): 535.621 Intermediate Fluid Dynamics and 535.641 Mathematical Methods for Engineers. Some programming experience is also assumed.

535.737 Multiscale Modeling and Simulation of Mechanical Systems

The successful design of complex engineering systems requires understanding physical processes that bridge multiple length and time scales. This course will introduce students to the fascinating field of multiscale modeling and provide a foundation for understanding systems/devices at a molecular, microscopic, and macroscopic levels. Through a combination of lectures, case studies and hands-on applications, students will learn (1) the principles that govern engineering systems at various length/time scales, and (2) how to develop, use, and hybridize multiscale simulation tools.

Instructor(s): Thomas

535.782 Haptic Applications

An introduction to the required theoretical and practical background in the design and development of haptic applications. Haptic technology enables users to touch and/or manipulate virtual or remote objects in simulated environments or tele-operation systems. This course aims to cover the basics of haptics through lectures, assignments, and readings on current topics in haptics.

Prerequisite(s): Recommended course background: graduate and senior undergraduate students who are enthusiastic to learn about haptics and basic familiarity with MATLAB.

Instructor(s): Zadeh

CHEMICAL AND BIOMOLECULAR ENGINEERING

545.203 Engineering Thermodynamics

This course covers the 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. 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.

Prerequisite(s): 540.202 Introduction to Chemical & Biological Process Analysis or permission of instructor.

Corequisite(s): AS.110.202 Calculus III (Calculus of Several Variables).

Course Note(s): Not for graduate credit.

Instructor(s): Bevan, Wang

545.204 Applied Physical Chemistry

The topics in this course include thermodynamic models for multicomponent phase equilibrium including vapor liquid equilibrium, phase diagrams, activity models and colligative properties in both non-electrolyte and electrolyte solutions. A link between average thermodynamic properties and microstates and molecular interactions is made via a discussion of intermolecular forces and the partition function. Also covered are thermodynamic relationships to describe chemical equilibria, and basic concepts in quantum mechanics and statistical mechanics.

Prerequisite(s): 540.203 Engineering Thermodynamics and either 540.202 Introduction to Chemical & Biological Process Analysis or permission of instructor. 540.xxx courses are offered through the full-time Chemical & Biomolecular Engineering Department.

Course Note(s): Not for graduate credit.

Instructor(s): Gracias

545.301 Kinetic Processes

Review of numerical methods applied to kinetic phenomena and reactor design in chemical and biological processes. Homogeneous kinetics and interpretation of reaction rate data. Batch, plug flow, and stirred tank reactor analyses, including reactors in parallel and in series. Selectivity and optimization considerations in multiple reaction systems. Non isothermal reactors. Elements of heterogeneous kinetics, including adsorption isotherms and heterogeneous catalysis. Coupled transport and chemical/biological reaction rates.

Prerequisite(s): 540.203 Engineering Thermodynamics and 540.303 Transport Phenomena I, and either 540.202 Introduction to Chemical & Biological Process Analysis or permission of instructor. 540.xxx courses are offered through the full-time Chemical & Biomolecular Engineering Department.

Course Note(s): Not for graduate credit.

Instructor(s): Cui, Goffin

545.303 Transport Phenomena I

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

Prerequisite(s): A grade of C or better in Calculus I and II and 540.202 Introduction to Chemical & Biological Process Analysis or permission of instructor. 540.202 is offered through the full-time Chemical & Biomolecular Engineering Department.

Corequisite(s): 500.303 Applied Mathematics I or AS.110.302.

Course Note(s): Not for graduate credit.

Instructor(s): Frechette, Konstantopoulos

545.304 Transport Phenomena II

Topics covered in this course include dimensional analysis and dimensionless groups, laminar boundary layers, introduction to turbulent flow, definition of the friction factor, macro-scopic mass, momentum and mechanical energy balances (Bernoulli's equation), metering of fluids, convective heat and mass transfer, heat and mass transfer in boundary layers, correlations for convective heat and mass transfer, boiling and condensation, and interphase mass transfer.

Prerequisite(s): 540.303 Transport Phenomena I. 540. xxx courses are offered through the full-time Chemical & Biomolecular Engineering Department.

Course Note(s): Not for graduate credit.

Instructor(s): Gagnon

545.602 Metabolic Systems Biotechnology

The aim of this course is to provide a fundamental understanding of the quantitative principles and methodologies of systems biology and biochemical engineering of metabolism. This includes concepts of cellular growth, cellular stoichiometric models, metabolic networks, metabolite fluxes, and genome-scale metabolic models. Quantitative methods and systems biology approaches for metabolic flux analysis and metabolic control theory will be included as well as an analysis of biochemical systems and bioreactors including a consideration of mass transport processes.

Instructor(s): Betenbaugh

545.603 Colloids and Nanoparticles

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

Instructor(s): Bevan

545.604 Transport Phenomena in Practice

This course will provide a review of core concepts of transport phenomena (momentum, heat, and mass transfer). Chemical and biomolecular engineering problems that are relevant in the areas of medicine, biomaterials, and physiology will be discussed. Application areas will range from oxygen transport in lungs and delivery in tissues as an example of a gas–fluid interface; Fluid flow and shear stress, with blood as an example of a non-Newtonian fluid; molecular transport using cellular transport as an example; filtration and separation (membranes) using the Kidney as an example; and drug delivery and pharmacokinetics.

Prerequisite(s): Previous experience with transport phenomena concepts will be helpful but is not required. Knowledge in vector calculus and differential equations is imperative for this course.

Instructor(s): Santhanam

545.606 Chemical and Biomolecular Separation

This course covers staged and continuous-contacting separations processes critical to the chemical and biochemical industries. Separations technologies studied include distillation, liquid-liquid extraction, gas absorption, membrane ultrafiltration, reverse osmosis, dialysis, adsorption, and chromatography. Particular emphasis is placed on the biochemical uses of these processes and consequently on how the treatment of these processes differs from the more traditional approach.

Course Note(s): Only with permission of the instructor. Co-listed with 540.306.

Instructor(s): Betenbaugh

545.614 Computational Protein Structure Prediction and Design

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

Prerequisite(s): Programming experience is helpful but not required.

Instructor(s): Gray

545.615 Interfacial Science with Applications to Nanoscale Systems

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

Instructor(s): Frechette

545.619 Project in Design: Alternative Energy 🏛

This course is a group design project (i.e., not a lecture course). In the class, student groups research the various forms of alternative energy and then model a real-world alternative-energy process. The goal of the project will be to develop a process model that is sufficiently complete and robust that it can be used to understand the important factor in the process design and/or operation. This design project is focused on the role of alternative energy in the US and world economies. The remainder of the course will be devoted to a technical and economic analysis of an alternative energy technology. This course is organized to replicate group project work as it is practiced in industry. The class is divided into groups (typically 3 or 4 students) and each group meets separately each week with the instructor. Hence, there are no regularly scheduled class times; student groups sign up for weekly meeting times using Starfish in Blackboard. These meetings typically will be 60 minutes long. The expectations and assignments for this course are quite different from most other courses. There are no weekly lectures by the instructor. Rather, each week each group will make a PowerPoint presentation on the week's topic or their progress on their project.

Prerequisite(s): 540.202 Introduction to Chemical & Biological Process Analysis; 540.203 Engineering Thermodynamics; 540.301 Kinetic Processes; and 540.305 Modeling and Statistical Analysis of Data for Chemical and Biomolecular Engineers.

Course Note(s): Graduate Level. Meets with 540.401 Projects in Design: Alternative Energy.

Instructor(s): Donohue

545.621 Project in Design: Pharmacodynamics 🏛

This is a design course in which the design projects will be to develop pharmacokinetic models of the human body that can be used to understand the temporal distribution, spatial distribution, and bioavailability of pharmaceutical drugs. The course (and software to be developed) will cover the spectrum of factors affecting pharmaceutical bioavailability including drug formulation, mode of dosing and dosing rate, metabolism and metabolic cascades, storage in fatty tissues, and diffusional limitations (such as in crossing the blood-brain barrier or diffusional differences between normal and cancerous cells). The goal is to develop process models of the human body that will predict pharmaceutical bioavailability as a function of time and organ (or cell) type and that will work for a wide variety of pharmaceuticals including small molecules, biologics, and chemotherapy agents. This course is organized to replicate group project work as it is practiced in industry. The class is divided into groups (typically 3 or 4 students) and each group will meet separately each week with the instructor. Hence, there are no regularly scheduled class times; student groups sign up for weekly meeting times using Starfish in Blackboard. These meetings typically will be 90 minutes long. The expectations and assignments for this course are quite different from most other courses. There are no weekly lectures by the instructor. Rather, each week each group will make a PowerPoint presentation on the week's topic or their progress on their project.

Instructor(s): Donohue

545.622 Introduction to Polymeric Materials 🏛

Polymeric materials are ubiquitous in our society, from nature-made proteins and polysaccharides to synthetic plastics and fibers. Their applications range from day-to-day consumables to high-performance materials used in critically demanding areas, such as aviation, aerospace, and medical devices. The objective of this course is to provide an introductory overview on the field of polymer science and engineering. Students will learn some basic concepts in polymer synthesis, characterization, and processing. With the basic concepts established, industrial applications of polymeric materials will be discussed in two categories: structural polymers and functional polymers. Structural polymers, including plastics, fibers, rubbers, coatings, adhesives, and composites, will be discussed in terms of their structure, processing, and property relationship with a flavor of industrial relevant products and applications. Future trends in developing environmentally friendly polymers from renewable resources (green polymer chemistry) will also be covered. Lectures on functional polymers will focus on their unique properties that are enabled by rational molecular design, controlled synthesis, and processing (e.g., supramolecular assembly and microfabrication). This class of specialty materials can find their use in high-performance photovoltaics, batteries, membranes, and composites and can also serve as smart materials for use in coatings, sensors, medical devices, and biomimicry.

Instructor(s): Cui

545.628 Supramolecular Materials and Nanomedicine 🏛

Nanomedicine is a quickly growing area that exploits the novel chemical, physical, and biological properties of nanostructures and nanostructured materials for medical treatments. This course presents basic design principles of constructing nanomaterials for use in drug delivery, disease diagnosis and imaging, and tissue engineering. Three major topics will be discussed, including (1) nanocarriers for drug delivery that are formed through soft matter assembly (e.g., surfactants, lipids, block copolymers, DNA, polyelectrolytes, peptides); 2) inorganic nanostructures for disease diagnosis and imaging (e.g., nanoparticles of gold and silver, quantum dots and carbon nanotubes); and (3) supramolecular scaffolds for tissue engineering and regenerative medicine. Students are expected to learn the physical, chemical and biological properties of each nanomaterial, the underlying physics and chemistry of fabricating such material, as well as their advantages and potential issues when used for biomedical applications. This course will also provide students opportunities for case studies on commercialized nanomedicine products. After this class, students should have a deeper understanding of current challenges in translating nanoscience and nanotechnology into medical therapies.

Instructor(s): Cui

545.630 Thermodynamics and Statistical Mechanics

In this course we will aim for understanding the thermodynamics of chemical and biomolecular systems. We will first review classical, macroscopic thermodynamics, covering concepts such as equilibrium, stability, and the role of thermodynamic potentials. Our goal will be to gain a feel for the generality of thermodynamics. Statistical mechanics provides a link between the mechanics of atoms and macroscopic thermodynamics. We will introduce this branch in two distinct ways: (1) following standard methods of developing concepts such as ensembles and partition functions, and (2) where we will treat the basis of statistical mechanics as a problem in inference. With this foundation, we will consider concepts relevant to understanding the liquid state. Chemical transformations in a liquid are of importance in much of chemistry and biology; quasi-chemical generalizations of the potential distribution theorem will be introduced to present these ideas. We hope to give an overview of modern developments relating equilibrium work to non-equilibrium work, as these are of increasing importance in studies on single molecule systems. Registration by instructor permission only.

Instructor(s): Wang

545.637 Application of Molecular Evolution to Biotechnology

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

Instructor(s): Ostermeier

545.639 Advanced Topics in Pharmacokinetics and Pharmacodynamics

This course involves a semester-long project in pharmacodynamics. Topics are chosen in consultation with instructor.

Instructor(s): Donohue

545.640 Micro- and Nanotechnology

The field of micro-/nanotechnology has been gaining tremendous momentum, as evidenced by an explosive rise in the number of publications, patents, and commercial activities. This is an introductory course intended to expose students to the field and real-world applications. Lectures will include an overview of scaling of material properties at the nanoscale, micro- and nanofabrication methods, and essential analytical tools of relevance to the field. All through the course, we will go over electronic, optical, and biological applications of emerging micro- and nanoscale devices and materials.

Instructor(s): Gracias

545.652 Advanced Transport Phenomena

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

Prerequisite(s): Undergraduate Transport Phenomena preferred.

Instructor(s): Gagnon

545.660 Polymer Physics

This course will cover the physics aspect of macromolecular/polymeric materials. We will discuss the molecular origin of key physical phenomena, such as chain relaxation, time temperature superposition, free volume, high-strain-rate behavior, phase transitions, flow and fracture, as well as physical aging. Many real-world examples will be used throughout the course. We will also discuss the recent advances in biopolymers, polymers for 3D printing, electro-spinning, and polymers for tissue engineering. Students should have introductory training in materials science.

Instructor(s): Xia

545.662 Polymer Design and Bioconjugation

This course will focus on conventional to most recent inventions on polymer and conjugation chemistry. Weekly lectures will include the reaction strategy, designs and characterization techniques, structure–property relationship, simplistic approaches, and versatile application-oriented solutions to biomaterials and tissue engineering-related challenges. Students will learn how to devise creative strategies and about process design and product development.

Prerequisite(s): Preliminary knowledge of organic chemistry is expected. No prerequisites for graduate students.

Instructor(s): Singh

545.665 Engineering Principles of Drug Delivery 🏛

Fundamental concepts in drug delivery from an engineering perspective. Biological organisms are viewed as highly interconnected networks where the surfaces/interfaces can be activated or altered "chemically" and "physically/mechanically." The importance of intermolecular and interfacial interactions on drug delivery carriers is the focal point of this course. Topics include drug delivery mechanisms (passive, targeted); therapeutic modalities and mechanisms of action; engineering principles of controlled release and quantitative understanding of drug transport (diffusion, convection); effects of electrostatics, macromolecular conformation, and molecular dynamics on interfacial interactions; thermodynamic principles of self-assembly; chemical and physical characteristics of delivery molecules and assemblies (polymer based, lipid based); significance of biodistributions and pharmacokinetic models; toxicity issues; and immune responses.

545.668 Introduction to Nonlinear Dynamics and Chaos 🏛

An introduction to the phenomenology of nonlinear dynamic behavior with emphasis on models of actual physical, chemical, and biological systems, involving an interdisciplinary approach to ideas from mathematics, computing, and modeling. The common features of the development of chaotic behavior in both mathematical models and experimental studies are stressed, and the use of modern data-mining tools to analyze dynamic data will be explored. Emphasis will be placed on the geometric/visual computer-aided description and understanding of dynamics and chaos.

Prerequisite(s): Knowledge of linear algebra and ordinary differential equations (at an undergraduate level); some computing experience is desirable.

Instructor(s): Kevrekidis

545.671 Advanced Thermodynamics and Kinetics in Practice 🏛

In this graduate-level course, we will cover important principles in thermodynamics and kinetics along with examples relevant to engineering practice. After a short review of the first and second laws of thermodynamics, we will move on to their application in engines and refrigeration. We will discuss the thermodynamic properties of systems consisting of pure species and mixtures and address phase equilibria. With the key thermodynamic concepts in place, we will discuss topics in kinetics, including the fundamentals of reaction rates, rate laws, multiple reactions, and nonelementary reaction kinetics. Finally, we will address how reactor type and properties, transport limitations, and phase equilibria influence reaction rate.

Instructor(s): Goffin, Pereira

545.672 Green Engineering, Alternative Energy and CO2 Capture/Sequestration 🏛

This course inherently combines green engineering, alternative energy and CO2 capture and storage into a concentrated semester lecture. Green Engineering applies the cost-effective design, commercialization, and use of chemical processes in ways that minimize pollution at the source, and reduce impact on human activities and the environment. After general discussion of applying environmental principles into various chemical processes, this course will switch the gear to apply these green engineering ideas into the energy production that has increasing and critical importance to our modern world, how to minimize the pollution and CO2 emission. There are two ways to follow: 1. Alternative Energy, which uses alternative resources rather than the current dominant fossil fuel for energy production. Alternative energy includes solar, hydro, bioenergy, geothermal, tidal, nuclear energy and et al. The detailed production processes, the long term perspective, policy and advantages/disadvantages over their counterpart, fossil fuel, will be discussed. 2. Fossil fuel with CO2 Capture and Storage. CO2 capture methods such as chemical solvents/chemical looping, membrane, oxy fuel combustion will be discussed and their technical benefits/limitations will be studied. The storage will cover geological methods (coal bed and saline aquifer), enhanced oil recovery, ocean storage, terrestrial and others. The technical details, cost, future trends and national/international policy (carbon taxes/markets) will be discussed in this course.

Instructor(s): Wang

545.673 Advanced Chemical Reaction Engineering in Practice 🏛

Chemical reaction engineering deals with the analysis on data and the design of equipment in which reactions occur. Reactors may contain one or more phases and be used to conduct chemical or biochemical transformations. The course will cover the fundamental aspects of kinetics, data acquisition, data interpretation, heterogeneous catalysis, and heat and mass transfer for each type of reactor. Special emphasis will be placed on the practical application of reaction engineering in the petrochemical, chemical, biochemical, and materials industries. The course will make students aware of the needs and opportunities for chemical reaction engineering in industry.

Instructor(s): Pereira

545.691 Chemical Engineering Modeling and Design for Graduate Students 🏛

This course is one part of a two-semester sequence in chemical and biomolecular engineering product design. It is intended for students in the Chemical and Biomolecular Engineering master's program. This course guides the student through the complex process of new product design. Product design concerns the recognition of customer needs, the creation of suitable specifications, and the selection of best products to fulfill needs. Students work in small teams to develop a new product idea, design the product, and then iterate on prototype development. Students report several times on their accomplishments, both orally and in writing. Time is allowed so that laboratory tests can be performed and/or prototypes can be built.

545.800 Independent Study

Permission of instructor required.

FINANCIAL MATHEMATICS

555.642 Investment Science

This is the key introductory course for the financial mathematics program and introduces the major topics of investment finance. The investment universe, its context of markets, and the flow of global capital are introduced. Details of equities, interest, bonds, commodities, forwards, futures, and derivatives are introduced to varying degree. The concepts of deterministic cash flow stream, valuation, term structure theories, risk, and single- and multi-period random cash flows are presented. Here the neoclassical theory of finance is introduced including the topics of efficient markets, the risk-return twins leading to the mean variance Capital Asset Pricing Model (CAPM), the efficient frontier, the intertemporal models, and Arbitrage Pricing Theory (APT). Some introductory models of asset dynamics (including the binomial model), basic options theory, and elements of hedging are also included in this course.

Course Note(s): This course is the same as 553.642 offered by through the full-time Applied Mathematics & Statistics department for the residence Master of Science in Engineering in Financial Mathematics.

Instructor(s): Faculty

555.644 Introduction to Financial Derivatives

This is the first of a two-course sequence devoted to the mathematical modeling of securities and the markets in which they are created and exchanged. The basic cash, hybrid, and derivative instruments are reviewed and set in a rigorous mathematical context. This includes equities, bonds, options, forwards, futures, and swaps, as well as their dealer, over-the-counter, and exchange environment. Models of the term structure of interest rates, spot rates and, the forward rate curve are treated; derived from cash instruments (e.g., bonds and interest rates like LIBOR) as well as from derivatives (such as Eurodollar futures and swaps). Principles of static, discrete, continuous and dynamic probabilistic models for derivative analysis (including the Weiner process, Ito's Lemma, and an introduction to risk-neutral valuation) are applied to develop the binomial tree approach to option valuation, the Black-Scholes-Merton differential equation, and the Black-Scholes formulas for option pricing.

Course Note(s): This course is the same as 553.644 offered by through the full-time Applied Mathematics & Statistics department for the residence Master of Science in Engineering in Financial Mathematics.

Instructor(s): Faculty

555.645 Interest Rate and Credit Derivatives

This is the second of a two-course sequence devoted to the mathematical modeling of securities and the markets in which they are created and exchanged. Focus turns to interest rate derivatives and the credit markets. The martingale approach to risk-neutral valuation is covered, followed by interest rate derivatives and models of the short rate process (including Heath, Jarrow & Morton and the Libor Market Model); analysis of bonds with embedded options and other interest rate derivatives (e.g., caps, floors, swaptions). Credit risk and credit derivatives, including copula models of time to default, credit default swaps, and a brief introduction to collateralized debt obligations will be covered. A major component of this course is computational methods. This includes data and time series analysis (e.g., estimation of volatilities), developing binomial and trinomial lattices and derivative analysis schemes, and numerical approaches to solving the partial differential equations of derivatives.

Prerequisite(s): 555.644 Introduction to Financial Derivatives

Course Note(s): This course is the same as 553.645 offered through the full-time Applied Mathematics & Statistics department for the residence Master of Science in Engineering in Financial Mathematics.

Instructor(s): Faculty

555.646 Financial Risk Measurement and Management

This course applies advanced mathematical techniques to the measurement, analysis, and management of risk. The focus is on financial risk. Sources of risk for financial instruments (e.g., market risk, interest rate risk, credit risk) are analyzed; models for these risk factors are studied and the limitation, shortcomings, and compensatory techniques are addressed. Throughout the course, the environment for risk is considered, be it regulatory or social (e.g., Basel capital accords). A major component of the course are the Value at Risk (VaR) and Conditional VaR measures for market risk in trading operations, including approaches for calculating and aggregating VaR, testing VaR, VaR-driven capital for market risk, and limitations of the VaR-based approach. Asset Liability Management (ALM), where liquidity risk as well as market risk can affect the balance sheet, is analyzed. Here, models for interest rate, spread, and volatility risks are applied to quantify this exposure. Another major component of the course is credit risk. Sources of credit risk, how measured risk is used to manage exposure, credit derivatives, techniques for measuring default exposure for a single facility (including discriminant analysis and Merton-based simulation), portfolio risk aggregation approaches (including covariance, actuarial, Merton-based simulation, macro-economic default model, and the macro-economic cash-flow model - for structured and project finance). Finally, there is a brief introduction to concepts and tools that remain valid for large and extreme price moves, including the theory of copulas and their empirical testing and calibration.

Course Note(s): This course is the same as 553.646 offered through the full-time Applied Mathematics & Statistics department for the residence Master of Science in Engineering in Financial Mathematics.

Instructor(s): Faculty

555.647 Quantitative Portfolio Theory & Performance Analysis

This course focuses on modern quantitative portfolio theory, models, and analysis. Topics include intertemporal approaches to modeling and optimizing asset selection and asset allocation; benchmarks (indexes), performance assessment (including Sharpe, Treynor, and Jenson ratios) and performance attribution; immunization theorems; alpha-beta separation in management, performance measurement, and attribution; Replicating Benchmark Index (RBI) strategies using cash securities/derivatives; Liability-Driven Investment (LDI); and the taxonomy and techniques of strategies for traditional management (Passive, Quasi-Passive [Indexing] Semi-Active [Immunization & Dedicated] Active [Scenario, Relative Value, Total Return and Optimization]). In addition, risk management and hedging techniques are also addressed.

Course Note(s): This course is the same as 553.647 offered through the full-time Applied Mathematics & Statistics department for the residence Master of Science in Engineering in Financial Mathematics.

Instructor(s): Faculty

555.648 Financial Engineering and Structured Products

This course focuses on structured securities and the structuring of aggregates of financial instruments into engineered solutions of problems in capital finance. Topics include the fundamentals of creating asset-backed and structured securities–including mortgage-backed securities (MBS), stripped securities, collateralized mortgage obligations (CMOs), and other asset-backed collateralized debt obligations (CDOs)–structuring and allocating cash-flows as well as enhancing credit; equity hybrids and convertible instruments; asset swaps, credit derivatives, and total return swaps; assessment of structure-risk interest rate-risk and credit-risk as well as strategies for hedging these exposures; managing portfolios of structured securities; and relative value analysis (including OAS and scenario analysis).

Course Note(s): This course is the same as 553.648 offered through the full-time Applied Mathematics & Statistics department for the residence Master of Science in Engineering in Financial Mathematics.

Instructor(s): Faculty

CIVIL ENGINEERING

565.604 Structural Mechanics

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

Course Note(s): This course is a requirement for the general Civil Engineering program and the Structural Engineering focus area.

Instructor(s): Harris

565.606 Geotechnical Engineering Principles

This course aims to review and reinforce knowledge of soil mechanics and geotechnical engineering principles for application in a variety of structural and civil engineering projects. The course presents examples of geotechnical engineering design problems. The course then discusses the origin of soil and types of soil, and various relations between weight and volume; methods used to characterize the index properties of soil, and classification of soil; theory of compaction; Darcy's law and the role of permeability, and the theory of two-dimensional seepage; stresses induced in soil by footing and other loading; compressibility of soil, and consolidation and consolidation settlements; shear strength of soil and the laboratory methods of determining shear strength parameters; theories of lateral earth pressure and their application to the analysis of retaining walls; fundamentals of slope stability analysis; fundamentals of the bearing capacity analysis of shallow foundations; and methods of subsoil exploration.

Prerequisite(s): 560.305 Soil Mechanics or equivalent. 560.305 is offered on-site through the full-time Civil Engineering Department.

Course Note(s): This course is a requirement for the general Civil Engineering program.

Instructor(s): Anandarajah

565.608 BIM Applications in Civil Engineering
This course will introduce students to basic building information modeling (BIM) theory with an emphasis on how BIM is used in the design and construction of buildings. Students will learn how to model basic architectural, structural, and MEP systems in buildings using Autodesk Revit and how to schedule various model elements and create 2D drawings from the 3D model. They will be introduced to algorithmically generated content using Autodesk Dynamo.
Instructor(s): Dreher

565.616 Applied Finite Element Methods
This course will introduce finite element methods for the analysis of solids and structures. The following topics will be considered: procedure for defining a mechanics problem (governing equations, constitutive equations, boundary and initial value problems); theory and implementation of the finite element method for static analysis using linear elasticity; and the verification/validation of results using finite element analysis software.
Instructor(s): Seif

565.619 Advanced Structural Analysis
The course will focus on matrix implementations of the stiffness method for the analysis of statically indeterminate structures such as plane/space trusses and plane/space frames. Computational aspects of the stiffness method will be discussed with connections made to commercial software. Linear elastic analysis will be the primary focus, but topics in nonlinear analysis will also be introduced.
Instructor(s): Guest

565.620 Advanced Steel Design
This course examines advanced designs of structural steel buildings including consideration of torsion, lateral-torsional buckling, local buckling, plate girder design, connection design, framing systems for seismic design, nonlinear frame behavior, and principles of stability per the Direct Analysis Method.
Prerequisite(s): 560.320/325 Structural Design I/II or equivalent. 560.320/325 are offered on-site through the full-time Civil Engineering Department.
Instructor(s): Wheaton

565.622 Advanced Reinforced Concrete Design
This intensive course covers reinforced concrete materials and specifications and includes the following topics: conception, analysis, and design of beams and columns, slabs, foundations and walls with emphasis on the ultimate strength method. Advanced seismic design topics are then covered building from the basic knowledge of reinforced concrete design.
Prerequisite(s): 560.320/325 Structural Design I/II or equivalent. 560.320/325 are offered on-site through the full-time Civil Engineering Department.
Instructor(s): Anindya

565.623 Bridge Design and Evaluation
Through lectures, design problems and existing bridge examples, this course illustrates basic bridge knowledge from preliminary design to final design of major structural components. The course covers conventional bridges and other bridge types, including concrete segmental box girders, arch bridges, and cable-stayed bridges. The course is not intended to provide students with intensive training in any particular area of bridge design. The course requires problem solving, a term project, and a final exam. A background in reinforced concrete design and steel design will be helpful in this course.
Course Note(s): Recommended Course Background: 560.320/325 Structural Design I/II or equivalent. 560.320/325 are offered on-site through the full-time Civil Engineering Department.
Instructor(s): Kite, Shafer

565.626 Design of Wood Structures
This course introduces students to the design of wood structures. Wood structures may be constructed of sawn lumber, glulam, or engineered wood products. The primary focus in this class is on light-framed low-rise wood buildings constructed of sawn lumber or glulam, but concepts related to heavy timber-framed structures and tall wood buildings using cross-laminated timber (CLT) are introduced. Structural behavior under gravity and lateral loads is emphasized, as are analysis and design of the components within the gravity and lateral load resisting systems. The current version of the National Design Specification (NDS) for Wood Construction is used.
Instructor(s): Sangree

565.628 Preservation Engineering I: Theory and Practice
The renovation of existing buildings often holds many advantages over new construction, including greater economy, improved sustainability, and the maintenance of engineering heritage and architectural character in our built environment. Yet, the renovation of existing structures presents many challenges to structural engineers. These challenges include structural materials that are no longer in widespread use (e.g., unreinforced masonry arches and vaults, cast iron, and wrought iron) as well as structural materials for which analysis and design practices have changed significantly over the last half-century (e.g., wood, steel, and reinforced concrete). This first course in the theory and practice of preservation engineering will include a review of the building code requirements related

to work on existing buildings and a discussion of the load paths (both vertical and horizontal) through such structures. Further, this course will begin its review of structural materials with those that were available prior to the Industrial Revolution-namely masonry and timber. The course will conclude with an overview of the response of wood structures to wind and seismic loads. Wood deterioration mechanisms and structural repair strategies for wood will also be presented.

Instructor(s): Farmer, Spivey, Meade

565.630 Prestressed Concrete Design

Topics include prestressed concrete concepts for both pre-tensioning and post-tensioning: materials, types of prestress, and prestress losses; design of sections for flexure, shear, torsion, and compression; load balancing technique; consideration of partial prestress, composite sections, and slab systems.

Prerequisite(s): 560.320/325 Structural Design I/II or equivalent. 560.320/325 are offered through the full-time Civil Engineering Department.

Instructor(s): Hayek

565.631 Preservation Engineering II: Theory and Practice

Building on the content in Preservation Engineering I: Theory and Practice, this course will begin with materials introduced at the start of the Industrial Revolution-namely with the beginning of the use of iron materials as major structural elements within buildings. The course will continue with the introduction of cast iron, wrought iron, and finally, structural steel members. After introducing iron materials the course will continue with the early use of reinforced concrete as a major structural material. The course will discuss the historic structural analysis methods associated with such materials and contrast such methods with more modern analytical approaches. It will also discuss concrete deterioration and repair methods. Concepts related to masonry facade investigation and repair will be presented along with the analytical methods associated with thin-shell masonry construction from the 19th and 20th centuries. The course will conclude with a review of the assessment and retrofit of historic foundations.

Prerequisite(s): 565.628 Preservation Engineering I: Theory and Practice

Instructor(s): Farmer, Meade, Spivey

565.633 Investigation, Diagnosis, and Rehabilitation

Why do buildings deteriorate, and how do we address this problem? This course examines the deterioration (by human and nature) of building materials and systems. Through lectures and a field trip, students will learn how to set up and execute an investigation, study the symptoms, diagnose the problems, determine what kinds of tests are needed, design the necessary repairs, and maintain existing systems.

Instructor(s): Parker, Rogers

565.636 Lateral Forces: Analysis and Design of Building Structures

From earthquakes to wind events, lateral forces constitute some of the most extreme loading conditions for which new and existing building structures must be analyzed and designed to resist. This course provides a fundamental yet practical introduction to the development and application of earthquake and wind loadings on building structures, the dynamic response and behavior of structures to lateral forces, and the bases and requirements for ductile design and detailing of steel, concrete, wood, and masonry lateral force resisting elements. The course will build on these analysis and design fundamentals to examine the technical considerations and methodologies for evaluating the lateral force resisting systems of existing, oftentimes monumental, building structures, and for designing and implementing repairs and retrofits to these lateral systems, including the application of Performance Based Design. This course is co-listed with 560.615.

Instructor(s): Staff

565.637 Preservation Engineering in the Urban Context

Technical expertise is fundamental to design and construction within and around historic buildings in the urban context. This course will cover topics related to both design and construction. For below-grade engineering, the course will cover underpinning, bracket piles, secant piles, slurry walls, tie-backs and general shoring approaches to building below or adjacent to existing constructions. For upward additions to existing construction, the course covers strengthening techniques (including temporary shoring and bracing, temporary access options, and temporary protection) and the requirements of the International Existing Building Code (IEBC). Each class will provide both technical guides and case studies, offering perspectives from guest speakers practicing the diverse range of professions tasked to meet this challenge.

Instructor(s): Matteo, Spivey

565.658 Natural Disaster Risk Modeling

This course will introduce the student to the disaster risk modeling process, including structure of catastrophe models and uses in loss estimation and mitigation; study and modeling of hazards (especially hurricanes and earthquakes; also flood, landslide, and volcanic); vulnerability assessment including simulation of building damage; and estimation of post-disaster injuries and casualties. Additional topics will include exposure modeling (building typology distribution); introduction to disaster economic loss modeling; interpretation of risk metrics (return periods, PML, AAL, VaR, TVaR) and their uncertainty and applicability to management and financial decision-making process; and elements of present and future risk, such as climate and exposure changes. Students will gain introductory experience in the use of GIS and simulation with MATLAB.

Instructor(s): Pita

565.664 Advanced Foundation Design

This course will introduce the principles and specifics of the geotechnical design of shallow and deep foundations. Topics include design of shallow foundations, including spread footings, combined footings and mat foundations; design of deep foundations, including single piles, pile groups and drilled shafts; design of laterally-loaded piles; construction monitoring and testing methods for driven piles; design of foundations for vibration control; foundations on difficult soils; underpinning; and design of buried culverts.

Prerequisite(s): 560.305 Soil Mechanics (or equivalent) or 565.606 Geotechnical Engineering Principles.

Instructor(s): Anandarajah

565.680 Marine Geotechnical Engineering VL

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(s): 560.305 Soil Mechanics or equivalent. 560.305 is offered through the full-time Civil Engineering Department.

Instructor(s): Mouring

565.682 Design of Ocean Structures

This course presents a review of structural design theory and practice related to ocean structures. Basic elements of ocean structures are designed using current engineering design codes developed by the American Institute of Steel Construction (AISC) and American Petroleum Institute (API). Topics include ocean environmental forces, material selection, foundation design, and analysis/design of ocean structures.

Instructor(s): Mouring

565.684 Port and Harbor Engineering VL

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.

Instructor(s): Mouring

565.686 Sustainable Coastal Engineering VL

This course presents a review of sustainable engineering related to the ocean environment. Sustainable shore protection designs will be investigated such as living shorelines and sills, beach nourishment, and other sustainable methods in order to adapt to coastal hazards such as hurricanes, tsunamis, and sea level rise. Sustainable energy such as coastal wind energy, wave energy, tidal energy, and other sustainable energy sources will be also investigated as alternative energy designs. The importance of sustainable food production will be discussed and aquaculture system designs such as ocean aquaculture, shellfish aquaculture, and other sustainable food production will be studied.

Instructor(s): Mouring

565.731 Structural Dynamics

This course provides an overview of rigid-body dynamics, free and deterministic forced vibration of undamped and damped single- and multi-degree-of-freedom systems, vibration of continuous systems, approximate methods of analysis, and introduction to random vibration of linear systems. Applications of the principles of structural dynamics to determine a structure's earthquake response are also covered. Instructor assumes that students who enroll in this course have a basic understanding of stiffness and stiffness matrices.

Prerequisite(s): 535.641 Mathematical Methods for Engineers.

Instructor(s): Ucak

565.732 Earthquake Engineering

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

Instructor(s): Harris

565.734 Wind Engineering

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

Instructor(s): Simiu, Yeo

565.762 Ground Improvement Methods

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

Prerequisite(s): 560.330 Foundation Design or equivalent and 565.606 Geotechnical Engineering Principles. 560.330 is offered on-site through the full-time Civil Engineering Department.

Instructor(s): Chen

565.764 Retaining Structures and Slope Stability

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

Prerequisite(s): 560.305 Soil Mechanics or equivalent. 560.305 is offered on-site through the full-time Civil Engineering Department.

Instructor(s): Chen

565.800 Independent Study in Civil Engineering

Permission of instructor required.

565.801 Independent Study in Civil Engineering

Permission of instructor required.

ENVIRONMENTAL ENGINEERING, SCIENCE, AND MANAGEMENT

575.601 Fluid Mechanics

This course introduces the principles of continuity, momentum, and energy applied to fluid motion. Topics include hydrostatics; ideal-fluid flow; laminar flow; turbulent flow; form and surface resistance with applications to fluid measurement; and flow in conduits and channels, pumps, and turbines.

Instructor(s): Haq

575.604 Principles of Environmental Engineering

This course addresses the wide range of environmental engineering fundamentals with quantitative analyses where applicable. Topics include mass and energy transfer and balances; environmental chemistry; mathematics of growth and decay; risk assessment and management; surface water pollutants, biological and chemical oxygen demands; eutrophication; water supply systems and drinking water standards; wastewater treatment systems and effluent standards; groundwater flow, contaminant transport, and remediation technologies; hazardous waste and pollution prevention; remedial and corrective actions at contaminated sites; air pollution sources, control technologies, and atmospheric stability; ambient air quality standards and indoor air quality; global temperature, greenhouse effect and warming potential; global energy balance, carbon emission, and stratospheric ozone depletion; solid waste management, landfill disposal, combustion, composting, and recycling; medical waste; and environmental law, ethics, and justice. Field trips are integrated into the classes.

Course Note(s): This course is required of all degree students studying environmental engineering, science, and management who do not possess an undergraduate degree in environmental engineering.

Instructor(s): Alavi, Kim, Overcash

575.605 Principles of Water and Wastewater Treatment

Water quality objectives and the chemical, physical, and biological processes necessary for designing and managing modern drinking water and wastewater treatment plants are described in the course. The principles of coagulation, flocculation, sedimentation, filtration, biological treatment, solids handling, disinfection, and advanced treatment processes are presented. The course serves as a basis for the more advanced courses: 575.745 Physical and Chemical Processes for Water and Wastewater Treatment, 575.706 Biological Processes for Water and Wastewater Treatment, and 575.746 Water and Wastewater Treatment Plant Design.

Prerequisite(s): 575.601 Fluid Mechanics or an equivalent course in fluid flow or hydraulics; two semesters of undergraduate chemistry.

Instructor(s): Davies-Venn, Movahed

575.606 Water Supply and Wastewater Collection

This course covers the fundamental but practical issues of water distribution systems and wastewater/stormwater collection systems. Specific topics of interest in water supply include water supply master planning; design of water storage facilities, water mains, and pumping stations; distribution-system water quality; and service connection issues. Topics covered under wastewater/stormwater collection include hydrology and hydraulics of stormwater/wastewater conveyance systems; design of stormwater detention and retention facilities; and collection system control technologies including green infrastructure. Also covered are regulations governing sanitary sewer overflows (SSOs) and combined sewer overflows (CSOs); public health, environmental, and economic impacts of SSOs and CSOs; sewer system evaluation and rehabilitation methods; stormwater best management practices; and the benefits and challenges of water reuse. Through research papers and discussion forums, students examine case studies that illustrate diverse practical situations and stimulate creative ideas for solving real-life design problems.

Prerequisite(s): 575.601 Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

Instructor(s): Davies-Venn

575.607 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, as well as the techniques for their remediation and disposal. Topics include radioactivity, the nucleoids, interaction of radiation with matter, shielding, dosimetry, biological effects, protection standards, sources of environmental radiation, risk evaluation, fate and transport analysis, cleanup standards, legal requirements, cleanup technologies, waste disposal, and case studies.

Instructor(s): Lightner

575.608 Optimization Methods for Public Decision Making

This course is an introduction to operations research as applied in the public sector. Public sector operation research involves the development and application of quantitative models and methods intended to help decision makers solve complex environmental and socio-economic problems. The course material is motivated by real-world problems and is presented in an environmental engineering-relevant context. Such problems include air pollution control, water resources management, transportation planning, scheduling, resource allocation, facility location, and biological conservation. Emphasis is placed on skill development in the definition of problems, the formulation of models, and the application of solution methodologies. Methodologies covered in this course include linear programming, integer programming, multi-objective optimization, and dynamic programming.

Instructor(s): Williams

575.611 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, cost-benefit analysis, engineering economics, and public sector pricing.

Instructor(s): Boland

575.615 Ecology

The course examines an introduction to the organization of individual organisms into populations, communities, and ecosystems and interactions between organisms, humans, and the environment. Topics include causation and prediction in ecology; evolution and natural selection; populations and competition; biodiversity, extinction, and conservation; the impact of forest fragmentation and deforestation on diversity, erosion and sedimentation; wetland ecology and restoration; succession, stability, and disturbance; eutrophication and the Chesapeake Bay; island biogeography; and global climate change. An independent project will be required regarding a field site visited by the student; the student will examine an ecological, conservation, or restoration event or issue about that site.

Instructor(s): Hilgartner

575.619 Principles of Toxicology, Risk Assessment, and Management

Risk assessment and risk management have become central tools in continued efforts to improve public safety and the environment within the limited resources available. This course introduces the basic concepts of environmental risk assessment, relative risk analysis, and risk perception, including identifying and quantifying human health impacts and evaluating ecological risk. The course describes legislative and regulatory initiatives that are attempting to base decisions on risk assessment, along with the controversy that surrounds such approaches. It also addresses specific federal requirements for risk analysis by industry. The course discusses the realities of using risk assessments in risk management decisions, including the need to balance costs and benefits of risk reduction, issues of environmental equity, accounting for the uncertainties in risk estimates, effective risk communication, and acceptable risk.

Instructor(s): Dellarco

575.620 Solid Waste Engineering and Management

This course covers engineering and scientific concepts and principles applied to the management of municipal solid waste (MSW) to protect human health and the environment and the conservation of limited resources through resource recovery and recycling of waste material. Topics include regulatory aspects and hierarchy of integrated solid waste management; characterization and properties of MSW; municipal wastewater

sludge utilization; hazardous waste found in MSW; collection, transfer, and transport of solid waste; separation, processing, combustion, composting, and recycling of waste material; and the landfill method of solid waste disposal, which encompasses guidelines for design, construction, operation, siting, monitoring, remedial actions, and closure of landfills. Permitting and public participation processes, current issues, and innovative approaches are also addressed.
Instructor(s): Alavi, Kim, Overcash

575.623 Industrial Processes and Pollution Prevention 💻
This course presents the pollution prevention and waste minimization concepts, terminologies, life cycle impacts, and management strategies. The course introduces available remediation techniques for industrial pollution control and prevention and examines specific applications to industries including biological, chemical, physical, and thermal techniques. Topics include current state of knowledge of pollution prevention approaches to encourage pollution prevention strategies, highlights of selected clean technologies and clean products, technical and economic issues, incentives and barriers to pollution prevention, and the role of different sectors in promoting pollution prevention. Pollution prevention and waste minimization techniques such as waste reduction, chemical substitution, production process modification, and reuse and recycling will be addressed with regard to selected industries.
Instructor(s): Engel-Cox

575.626 Hydrogeology 💻
This course is an introduction to groundwater and geology and to the interactions between the two. It provides a basic understanding of geologic concepts and processes, focusing on understanding the formation and characteristics of water-bearing formations. The course also addresses the theory of groundwater flow, the hydrology of aquifers, well hydraulics, groundwater-resource evaluation, and groundwater chemistry. The relationship between the geologic concepts/processes and the groundwater resource are discussed. Examples include a discussion of the influence of the geologic environment on the availability and movement of groundwater and on the fate and transport of groundwater contaminants. Geotechnical engineering problems associated with groundwater issues are also covered.
Instructor(s): Barranco, Root

575.628 Business Law for Engineers 💻
This course introduces engineers to the basic legal principles they will encounter throughout their careers. Course discussions cover contracts (formation, performance, breach, and termination), corporations and partnerships, insurance, professional liability, risk management, environmental law, torts, property law, and evidence and dispute resolution. The course emphasizes those principles necessary to provide engineers with the ability to recognize issues that are likely to arise in the engineering profession and introduces them to the complexities and vagaries of the legal profession.
Instructor(s): Reynolds

575.629 Modeling Contaminant Migration through Multimedia Systems 💻
This course addresses contamination that can affect many media as it migrates through the environment. Typically, contaminant sources occur in soil, from which the chemicals then migrate to air, surface water, and groundwater. Predicting the movement of contaminants through these media requires addressing the fate and transport processes that predominate in each medium and integrating the interactions between the media. The course presents the basic principles and numerical methods for simulation contaminant migration from soil into and through surface-water bodies, air, and groundwater. The basic processes of fate and transport in the various media will be addressed: entrainment, adsorption, volatilization, chemical reactions such as degradation and photolysis, convection, and Gaussian dispersion and deposition. Selected public-domain numerical models will be used to simulate the fate and transport processes. Central to the course will be a project that integrates multimedia environmental modeling through a case study.
Instructor(s): Robert, Root, Stoddard

575.635 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.
Instructor(s): Gorski, Henderson

575.637 Environmental Impact Assessment 💻
This course examines principles, procedures, methods, and applications of environmental impact assessment. The goal of the course is to promote an understanding of how environmental impact assessment is conducted and used as a valuable tool in the engineering project management decision-making process. Topics include an overview of environmental

impact assessment; selection of scientific, engineering, and socioeconomic factors in environmental impact assessment; identification of quantitative and qualitative environmental evaluation criteria; application of traditional and other techniques for assessing impacts of predicted changes in environmental quality; approaches for identifying, measuring, predicting, and mitigating environmental impacts; modeling techniques employed in environmental impact assessment; environmental standards and the environmental impact assessment process; and methodologies for incorporating environmental impact assessment into management decision making. Students learn to prepare an environmental impact assessment, review and critically analyze an environmental impact statement, use mathematical models for environmental impact prediction, and apply environmental impact assessment as a tool in management decision making. Case studies of environmental impact assessment for several types of engineering projects are employed.

Instructor(s): Toussaint

575.640 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. Completion of a term project is required.

Instructor(s): Roper

575.643 Chemistry of Aqueous Systems

This course examines the chemical principles necessary to understand water quality and contaminant fate in natural and engineered aqueous systems. Quantitative problem-solving skills are emphasized. Specific topics include acid-base reactions, carbonate chemistry, oxidation-reduction reactions, and metal speciation. Case studies applying fundamental principles to important environmental phenomena (e.g., eutrophication of surface waters, drinking water treatment, soil/subsurface contamination, mobility of radioactive metals, ocean acidification, and geoengineering) are key components of this course.

Instructor(s): Sivey

575.645 Environmental Microbiology

This course covers fundamental aspects of microbial physiology and microbial ecology. Specific areas of focus include energetics and yield, enzyme and growth kinetics, cell structure and physiology, metabolic and genetic regulation, microbial/environmental interactions, and biogeochemical cycles. The goal of this course is to provide a basic understanding and appreciation of microbial processes that may be applicable to environmental biotechnology.

Instructor(s): Wadhawan

575.658 Natural Disaster Risk Modeling

Natural hazards such as floods, earthquakes, and hurricanes exert a heavy toll of victims and economic losses every year. Yet, concentrations of population in hazard-prone-areas, the growth of infrastructure and climate change are aggravating the risk of future losses. Consequently, adequate interventions must be implemented to mitigate the damaging effects of natural hazards. To do this, public agencies, non-profits, and companies formulate mitigation actions such as emergency preparedness plans and building retrofits. Catastrophe models are tools to inform all these efforts, which simulate the socioeconomic risk resulting from the interaction of geophysical events and the spatial distribution of infrastructure.

Instructor(s): Pita

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(s): Prior coursework in environmental microbiology or biochemical engineering is recommended but not required.

Instructor(s): Wadhawan

575.704 Applied Statistical Analyses and Design of Experiments for Environmental Applications

This course introduces statistical analyses and techniques of experimental design appropriate for use in environmental applications. The methods taught in this course allow the experimenter to discriminate between real effects and experimental error in systems that are inherently noisy. Statistically designed experimental programs typically test many variables simultaneously and are very efficient tools for developing empirical mathematical models that accurately describe physical and chemical processes. They are readily applied to production plant, pilot plant, and laboratory systems. Topics covered include fundamental statistics; the statistical basis for recognizing real effects in noisy data; statistical tests and reference distributions; analysis of variance; construction, application, and analysis of factorial and fractional-factorial designs; screening designs; response surface and optimization methods; and applications to pilot plant and waste treatment operations. Particular emphasis is placed on analysis of variance, prediction intervals, and control charting for determining statistical significance as currently required by federal regulations for environmental monitoring.

Instructor(s): 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.

Prerequisite(s): 575.605 Principles of Water and Wastewater Treatment.

Instructor(s): Weiss

575.707 Environmental Compliance Management

The course covers compliance with environmental laws and regulations by industry, small business, government facilities, and others. It includes legal responsibilities, environmental management systems, and practices such as audits and information systems and development of corporate policies and procedures that rise to the daunting challenge to harmonize the institution's primary goals with its environmental obligations. Several dimensions of environmental management are discussed: federal, state, and local regulation; scientific/technical factors; public relations and the press; and institutional objectives including economic competitiveness.

Instructor(s): Riegel

575.708 Open-Channel Hydraulics

The course covers application of the principles of fluid mechanics to flow in open channels. Topics include uniform flow, flow resistance, gradually varied flow, flow transitions, and unsteady flow. The course also addresses flow in irregular and compound channels, backwater and 2D flow modeling, and applications to channel design and stability.

Prerequisite(s): 575.601 Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

Instructor(s): Naghash

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, along with their relative desirability and efficiency. Since grant funding is never available for all projects, the course deals extensively with borrowing/lending. It discusses strategies for maximizing utility income, including appropriate tariff structures and the reform of government subsidy policy from supply-based general subsidies to demand-based targeted subsidies. Operational strategies to maximize income are also discussed, such as techniques to improve billing and collections, reduce losses, and reduce energy costs. Traditional cash flow analyses are used to determine debt service capabilities. Various project cost reduction strategies, such as staging and scaling, are introduced. Grants in the form of upfront project cost buy-downs vs. annual debt service subsidies are compared. Finally, several examples of project financings combining many of the elements introduced during the course are presented and analyzed.

Instructor(s): Reynolds

575.711 Climate Change and Global Environmental Sustainability

This is a multidisciplinary course that focuses on the critical assessment of science, impacts, mitigation, adaptation, and policy relevant to climate change and global environmental sustainability. The first half of the class addresses climate change science; vulnerability and existing evidence and observations of the impacts of climate change; models and predictions of potential physical, ecological, and anthropological impacts; technological, economic, political, and consumer driven mitigation and adaptation strategies; and past and present local, state, federal, and international policy and legislation. The second half of the course actively investigates concepts and aspects of environmental sustainability, including the review of international assessments and reports and the analyses of relevant implications for human health, natural resources, energy supply and demand, and waste/pollution. This course stresses active learning and critical thinking. It requires both the objective and subjective analyses of an array of environmental sustainability and climate change topics and materials. Students will be required to participate in a climate change summit simulation, critically review climate change documentaries and complete an original timely and relevant sustainability case study. Students will also be required to complete quantitative technical assignments; research popular press, governmental agency, and peer-reviewed scientific literature; and participate in class discussions, presentations and exercises.

Instructor(s): Robert

575.713 Field Methods in Habitat Analysis and Wetland Delineation

This 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, abundance and diversity, including the quadrat and transect-based, point-intercept, and plot-less methods; identification of common and dominant indicator plant species of wetlands and uplands; identification of hydric soils; and the use of soil, topographic and geologic maps and aerial photography in deriving a site description and site history. Emphasis is placed on wetland vegetation, delineation and restoration. While many of the field examples are centered in the Maryland and Washington, DC region, the format is designed so that the student performs field work in the state, country or region in which he or she would like to specialize.

Prerequisite(s): 575.615 Ecology.

Instructor(s): Hilgartner

575.714 Water Resources Management

This multidisciplinary course examines the scientific, institutional, and analytical aspects of managing water quantity and quality. Students are provided a historical context that is useful for assessing current policy. The water cycle and basic hydrology are reviewed. The course surveys the laws and regulatory instruments for managing water quantity and quality, which operate across federal, state, and local levels of government. Funding issues associated with water resources management include operating and capital budgets, debt financing, the challenges of pricing, and the role of privatization. The course addresses the management of water supply and demand in the United States by economic sector and by in-stream and off-stream uses. This includes trends in water supply and demand, as well as modeling methods for water supply management. Fundamentals of flood and drought management are covered, with attention given to the context of global climate change and extreme events. The critical role of the general public in water resource management decision making is addressed in the context of structured techniques involving economic analyses, multi-objective analyses, and collaborative decision making. Water quality-based management under the federal Clean Water Act includes the topics of water quality standards, water quality assessments, total maximum daily loads (TMDLs), and ensuing permit requirements. Regional ecological water resources management is addressed for the Susquehanna River and by contrasting the Chesapeake Bay case with other large-scale cases.

Instructor(s): George, Williams

575.715 Subsurface Fate and Contaminant Transport

This course provides an introduction to the concepts relating to the nature and sources of environmental contaminants in the subsurface, the role of groundwater and soil water in mobilizing and spreading contamination, the processes that control distribution and fate of subsurface contamination, the accepted methods of investigating and analyzing contamination, and the analytical techniques that can be employed to model contaminant fate and transport in the subsurface. The course also considers surface water contamination caused by contamination in the groundwater. Computer laboratories of groundwater model simulations and solute transport solutions are used.

Instructor(s): Ashfaque, 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 focuses on the tidal waters of the Chesapeake Bay and its tributaries. It also covers the relationships of the bay with the surrounding watershed, atmosphere, and ocean as well as relevance to other coastal systems. Particular emphasis is on to anthropogenic stresses such as nutrient and contaminant pollution, habitat modification, and harvest of fish and shellfish. The most current Chesapeake Bay management issues and policies being pursued at the federal, state, and local levels of government are discussed in depth, including their scientific foundation.

Instructor(s): Overcash, Summers

575.717 Hydrology

This course introduces the fundamental physical principles that are necessary to understand the occurrence, distribution, and circulation of water near Earth's surface. Students will be introduced to the global hydrological cycle and the influence of climate, geology, and human activity. Students will study the processes of precipitation and evapotranspiration; surface water flow, floods, and storage in natural and artificial reservoirs; groundwater flow; and whole-cycle catchment hydrology. Although less emphasized, water-quality and water resources management issues will be discussed and case studies presented. Throughout the course, a quantitative approach is taken in which mathematical descriptions of hydrological phenomena will frequently be an objective. The course will also provide an introduction to hydrological data acquisition and analysis.

Prerequisite(s): 575.601 Fluid Mechanics or an equivalent course in fluid flow or hydraulics.

Instructor(s): Raffensperger

575.720 Air Resources Management and Modeling

This course focuses on air pollution management and modeling topics with an emphasis on how air quality models can be used to help inform decision makers. In addition to introducing the fundamentals of air pollution and addressing general modeling considerations, topics covered in this course include the health and environmental effects of key air pollutants, how air quality modeling was used in major studies leading to better air quality, US requirements for air quality modeling studies, and current local, national, and international air pollution issues. Atmospheric physics and chemistry are reviewed as they relate to air pollutant transport and transformation. Specific modeling topics include box and plume models, indoor air quality and monitoring, numerical and statistical models, and climate change modeling and decision making. Specific air pollution problems addressed in the course include those at local, regional, and national scales; air pollution problems from a public health perspective; and approaches for developing air pollution control strategies for various air pollutants. A term-long case study assignment is required that leverages these course elements to address a timely and relevant real-world air pollution scenario.

Instructor(s): Robert, Wierman

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.

Prerequisite(s): 575.601 Fluid Mechanics or an equivalent course in fluid flow; an undergraduate course in thermodynamics.

Instructor(s): Robert

575.722 Sensor Applications for Environmental Monitoring and Exposure Assessment

The primary objective of this course is to present the fundamentals of sensor design in the application of environmental monitoring. The course will examine the basic sensor design and operation in specific environmental applications including ambient, built, personal, and social. Other topics to be covered include, data capture, storage, transmission, as well as analysis of the legal and policy requirements for environmental monitoring with sensors.

Instructor(s): Dellarco

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, the course will explore sustainable building concepts 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 with a review of example projects. Integrated design and construction practices that significantly reduce or eliminate the negative impact of buildings on the environment and occupants will be assessed in the broad areas of (1) sustainable site planning, (2) safeguarding water and water efficiency, (3) energy efficiency and renewable energy, (4) conservation of materials and resources, and (5) indoor environmental quality. A critical element for a successful sustainable building policy and program is an integrated building planning and design process. Integrated planning and design refers to an interactive and collaborative process in which all stakeholders are actively involved and communicate with one another throughout the design and construction practice. These processes will also provide a broader understanding of sustainable options for infrastructure changes that may occur in various BRAC planning and implementation situations. A number of case studies will be examined to gain an understanding of application issues.

Instructor(s): Roper

575.727 Environmental Monitoring and Sampling

Environmental monitoring and sampling provide the data foundation required for assessments of (1) compliance with environmental criteria and regulatory permits, and (2) status and trends to evaluate the effectiveness of legislation and regulatory controls. The overall objective of the course is to prepare a Sampling and Analysis Plan (SAP) as a course project to support a site-specific field data collection program that includes environmental sampling for air, surface water, groundwater, and soils. An overview of historical and current environmental issues, including public health and environmental impacts, for air, surface water, groundwater, and soil contamination, is presented. Regulatory requirements of the major statutes that govern various media are presented, along with assessments of the effectiveness of legislation including the Clean Water Act, Clean Air Act, Safe Drinking Water Act, CERCLA, and RCRA. The course describes sources and physical, chemical, and biological processes that govern distributions of contaminants in air, surface water, groundwater, and soils. The course examines the principles, methods, and strategies for monitoring and discrete sampling of environmental media, including air, surface water, groundwater, and soil. Sampling methods include overviews of current methods for discrete sampling, automated data acquisition, and remote sensing for air, surface water, groundwater, and soils. Requirements of a SAP will be presented, including key elements of a Quality Assurance Project Plan (QAPP) and a Field Sampling Plan (FSP.) The course presents key concepts of statistics for sampling design, data variability, and analysis and interpretation of data sets. The course includes an introduction to data sources available from national databases for air, surface water, groundwater, and soils. Analysis, presentation, and interpretation of data sets include use of GIS/mapping, data management methods, and statistical analyses to support decision-making, site characterization, and evaluation of status and trends. Where feasible, the online course will provide the opportunity for students to participate in local field trips or observe field sampling methods for air, surface water, groundwater, and soils.

Instructor(s): Ashfaque, Robert, 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.

Prerequisite(s): A course in fluid mechanics or an equivalent course in fluid flow or hydraulics.

Instructor(s): Gellis

575.730 Geomorphic and Ecologic Foundations of Stream Restoration

This course presents principles from hydrology, sedimentation engineering, geomorphology, and ecology relevant to the design and evaluation of stream restoration projects. A watershed context is emphasized in developing the background needed to assess different design approaches. After developing a common foundation in stream dynamics, the course considers trade-offs among restoration objectives, the merits of analog and predictive approaches, the role of uncertainty in restoration design, and metrics for assessing ecological recovery. The course includes online discussions, design exercises, and review papers and finishes with an assessment of a stream in students' geographic regions.

Instructor(s): Baker, Sholtes

575.731 Water Resources Planning

The course will discuss the application and interrelationships among microeconomics, ecology, hydrology, and fields related to the planning and management of water systems. Topics will include flood control, navigation, hydroelectric power, water supply, environmental restoration, multi-objective planning, and urban water resource 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.

Instructor(s): Kranzer

575.733 Energy Planning and the Environment

This course examines the interrelationships between the environment and the ways in which energy is produced,

distributed, and used. Worldwide energy use patterns and projections are reviewed. Particular attention is paid to the electrical and transportation sectors of energy use. Underlying scientific principles are studied to provide a basis for understanding the inevitable environmental consequences of energy use. Topics studied include fossil, nuclear, and existing and potential renewable sources, including hydroelectric, geothermal, tidal, wind, and solar. Transportation options including internal combustion, hybrid, and electric options are quantitatively compared. Use of alternate fuels such as biodiesel and ethanol are evaluated. Emphasis is placed on the environmental impacts of energy sources, including local effects resulting from emissions of nitrogen oxides, sulfur, hydrocarbons, and particulates as well as global effects such as mercury release from coal combustion. Carbon emissions are a continuing theme as each energy technology is studied and its contribution to climate change is assessed. Carbon suppression schemes are examined. Particular attention is paid to consequences and effectiveness of government intervention and regulation. The purpose is to help students understand how energy is converted into useful forms, how this conversion impacts our environment, and how public policy can shape these impacts.
Instructor(s): Lightner

575.734 Smart Growth Strategies for Sustainable Urban Development and Revitalization

This course addresses the concepts, practices, and tools for smart growth sustainable urban planning and provides an understanding of how to apply these to urban communities. The sustainable urban development is a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present but also for future generations to come. In other words, it is the development and restoration of urban areas that will meet the needs of the present without compromising the ability of future generations to meet their own needs. The course addresses a number of urban design concepts for smart growth and sustainable development, including balanced land use planning principles; importance of an overall transportation strategy; providing urban tree coverage; leveraging public transportation accessibility; providing a spectrum of housing availability; integration of office, retail, and housing units; reduction of urban area environmental footprint; use of recycled, reused, reusable, green, and sustainable products; integration of renewable solar energy and wind power into buildings and government systems; transit-oriented development; innovative low-impact storm water management practices; reduction in urban heat island effects; urban water resource management; and energy efficiency and conservation.
Instructor(s): Roper

575.735 Energy Policy and Planning Modeling

This course provides students with comprehensive knowledge on methods for optimizing operation and design of energy systems and methods for analyzing market impacts of energy and environmental policies with emphasis on both theory and solution of actual models. The course also covers linear and nonlinear programming and complementarity methods for market simulation.
Prerequisite(s): Microeconomics or optimization methods (linear programming).
Instructor(s): Fisher

575.736 Designing for Sustainability: Applying a Decision Framework

In this course, students will apply a sustainability decision framework, developed by the National Research Council, to an environmental project of their choice. This will include developing a project management plan, a project action plan, and an evaluation and adaptation assessment that will outline how sustainability principles will be incorporated into their project. This applied approach will give students experience in systems thinking, linkages across governmental bodies, development of indicators, use of environmental support tools, transdisciplinary cooperation, and the use of structured decision framework.
Instructor(s): Kopsick

575.737 Environmental Security with Applied Decision Analysis Tools

This multi-disciplinary course examines current and emerging environmental security issues at multinational, national, and regional scales. These issues are approached from the perspective of decision-making for policy, planning, and management. The course begins with an overview and definitions of environmental security within the context of present global demographic patterns, use of natural resources, and climate change. The theory and principles of multi-criteria decision analysis (MCDA) are reviewed, using environmental security examples to illustrate concepts. Three MCDA methodologies are presented, including multi-attribute weighting, Analytic Hierarchy Process, and outranking, which are commonly used to assist decision makers. The MCDA approach is critiqued from the perspective of measurement theory and guidelines for MCDA use are suggested. With both the social sciences and natural sciences providing a framework, several specific environmental security topics are covered in greater depth: energy; air quality; ecosystems and biodiversity; fresh water; agriculture and food; and sea level rise. Within these topics, students will develop MCDA models for particular policy, planning, and management problems under the guidance of the instructors. The course concludes by considering the prospects for environmental security and sustainability in the coming decades.

Instructor(s): Williams, Wolman

575.741 Membrane Filtration Systems and Applications in Water and Wastewater Treatment

This course covers fundamentals of membrane filtration technology and application in municipal and industrial water and wastewater treatment. Topics include membrane classification, mechanism of separation/filtration, principle of operation, performance monitoring, maintenance, pilot scale testing, residual disposal, emerging and developing membrane separation technologies, and regulations governing treatment objectives and residual disposal in membrane filtrations systems. This course provides students with in-depth knowledge of the theory, application, and design of membrane filtration systems by engaging them in group assignments and design projects.

Instructor(s): Jankhah

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; hazardous waste generators and transporters; permitting and enforcement of hazardous waste facilities; closure and financial assurance requirements; RCRA Corrective Action and CERCLA/Superfund/Brownfields site remediation processes; groundwater flow and 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; and pollution prevention and waste minimization.

Instructor(s): Alavi, Kim, Overcash

575.743 Atmospheric Chemistry

Earth's atmosphere is a vital and fragile component of our environment. This course covers the chemical composition of the atmosphere and the principles of chemistry that control the concentrations of chemical species. Following an introduction to the atmosphere, including its structure and composition, the course investigates basic concepts relating to atmospheric chemical kinetics and photochemistry. This foundation of chemistry and physics is applied to the study of the gas-phase chemistry of the troposphere and the stratosphere including focused study of criteria pollutants such as carbon monoxide (CO), tropospheric and stratospheric ozone (O_3), chlorinated fluorocarbons (CFCs), sulfur and nitrogen oxides (NOx and SOx) and particulate matter (PM). Many trace species and their impacts on atmospheric chemistry are investigated. Condensed-phase chemistry topics include aqueous-phase chemistry, the chemistry of clouds and fogs and aerosol chemistry (including particulate matter chemistry). The chemistry of climate change and the radiative forcing of atmospheric constituents is studied. The relationship between atmospheric chemistry and air quality is stressed via focusing on negative human health and environmental impacts. The course stresses application of these concepts to current and relevant atmospheric chemistry issues.

Instructor(s): Jakober, Robert

575.744 Environmental Chemistry

This course focuses on the environmental behavior and fate of anthropogenic contaminants in aquatic environments. Students learn to predict contaminant properties influencing contaminant transfers between hydrophobic phases, air, water, sediments, and biota, based on a fundamental understanding of physico-chemical properties, intermolecular interactions, and basic thermodynamic principles. Mechanisms of important transformation reactions and techniques and quantitative models for predicting the environmental fate or human exposure potential of contaminants are discussed.

Instructor(s): Jayasundera

575.745 Physical and Chemical Processes for Water and Wastewater Treatment

In this course, mass and momentum transport, aquatic chemistry, and chemical reaction engineering are applied to physical and chemical processes used for water and wastewater treatment. Students also learn the theory and practice of various unit processes including disinfection, oxidation, coagulation, sedimentation, filtration, adsorption, gas transfer, and membrane filtration. The goal is to provide a theoretical understanding of various chemical and physical unit operations, with direct application of these operations to the design and operation of water and wastewater treatment systems. Students will use the concepts learned in this class to better understand the design and operation of engineered and natural aquatic systems.

Prerequisite(s): 575.605 Principles of Water and Wastewater Treatment.

Instructor(s): 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.

Prerequisite(s): 575.605 Principles of Water and Wastewater Treatment and either 575.706 Biological Processes for Water and Wastewater Treatment or 575.745 Physical and Chemical Processes for Water and Wastewater Treatment.

Instructor(s): Arora, Davies-Venn

575.747 Environmental Project Management

This course educates students on the key elements of an integrated approach to environmental project management, an endeavor that requires expertise in scientific, engineering, legal, public policy, and project management disciplines. Emphasis is placed on critical factors that are often unique to a major environmental project, such as the uncertainty surrounding scope definition for environmental cleanup projects and the evolving environmental regulatory environment. The students learn to develop environmental project plans, establish project organization and staffing, define management functions, develop time management approaches, resolve project conflicts, determine project effectiveness, and 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 trade-off 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.

Instructor(s): Toussaint

575.750 Environmental Policy Needs in Developing Countries

This course will provide students with a thorough understanding of environmental policy needs in developing countries. The world's fastest growing economies are located in developing countries where rapid urbanization and use of natural resources will require supporting infrastructure. However, there are factors that may encourage or limit this growth, including the country's economic structure, governance, cultural history, demographics, and social structure. Through lectures, research, and group exercises, the students will (1) explore the social, economic, and environmental issues that challenge countries in the developing world as they move toward advancing their economies, infrastructure, and governance systems; (2) analyze how the various issues are interconnected and understand how this interconnectedness may affect environmental policy making; and (3) apply critical thinking to the analysis of environmental policy in order to effectively challenge classical assumptions. The student will be expected to analyze a specific environmental issue facing a developing country or region and develop a policy framework to address this issue.

Instructor(s): Kopsick

575.752 Environmental Justice and Ethics Incorporated into Environmental Decision Making

This course focuses on the environmental justice and ethics problems facing environmental engineers, planners, and managers. It explores the foundations of the environmental justice movement, current and emerging issues, and the application of environmental justice analysis to environmental policy and planning. It examines claims made by diverse groups along with the regulatory and government policy responses that address perceived inequity and injustice. The course will study the mechanisms that give rise to class, racial, and other kinds of disparities that impact environmental decision-making. This includes the study of affected constituents, communities, industry, government, environmental activists, policy makers, and scholars, allowing students to learn about the causes and consequences of inequitable distributions of environmental benefits and hazards. Students will learn about various methods for researching environmental justice issues and strategies for formulating policies and collaborating with communities. In this course, students will review environmental justice theories and perspectives through case studies of Black Americans, Hispanic Americans, and Native American Nations. The class will focus mainly on the United States, but will include aspects of international issues and perspectives through research projects.

Instructor(s): Tzoumis

575.753 Communication of Environmental Information and Stakeholder Engagement

This course provides students with the skills for communicating scientific environmental data and sustainable engineering design to stakeholders, including scientists in different fields, policy decision makers, and the interested public. The course covers the importance of clear communication of complex scientific information for the development and acceptance of technologies, public policy, and community-based environmental initiatives. The key stakeholders for environmental engineers, scientists, and managers are specified. Methods of engagement and designing key messages are defined for global, national, and local issues of student interest. Major types of communication media are covered, including written communication and graphics, online communications in short- and long-form new media, and interactive communications such as surveys and citizen science to involve stakeholders in the creation and analysis of big data and dispersed information. The emphasis of the course is from the point of view of an environmental professional (not a marketing professional) and developing an effective science-based communications portfolio to share complex scientific information with a broad range of interested parties.

Instructor(s): Engel-Cox

575.759 Environmental Policy Analysis

The course explores the process of analyzing environmental policies to ensure human health, that environmental needs are protected, and that the physical environment is preserved, protected, and restored, if necessary. Emphasis is placed on the need to evaluate and make decisions regarding environmental science, human health, sociopolitical, technological, legal, and economic considerations in a context of incomplete information and uncertain futures. Case studies and policies relating to various contemporary environmental issues, for example hazardous waste disposal, natural resource extraction and preservation of natural resources, are critiqued during the semester. The course will lead students through the various steps of the policy analysis process. Students are expected to evaluate policy alternatives, develop evaluation criteria, and apply qualitative and quantitative methods to determine consequences, trade-offs, and potential synergies relating to these environmental issues. Students will then use these skills to create and execute an individual research project that analyzes an environmental policy relating to a specific issue of interest to them, evaluating potential responses to environmental management problems through analyzing the impacts of each policy alternative.

Instructor(s): Kopsick

575.761 Measurement Theory and Practices in the Environmental Arena

In this course, students will critically investigate practical, theoretical, mathematical, philosophical, sociological, and legal aspects of measurement in environmental science and related disciplines. Quantification, or claims thereto, underpin analysis, research, policy, and decision making in the environmental arena. To this end, students will explore the theoretical and mathematical bases for quantification and trace the relationship between these bases and the role played by quantification in environmental research and policy. Students will approach three theories of measurement—traditional, representational, and operational—from historical, technical, mathematical, and philosophical perspectives, and critically analyze application of these measurement paradigms in a number of environmental contexts including those associated with river systems and hydrology.

Instructor(s): Grant, Wolman

575.762 Resilience of Complex Systems

This course will present a subset of the mathematical techniques often use to gain an understanding of the response of complex systems to acute events and compound threats. Examples of complex systems include: installations, organizations, communities, etc. With the understanding of resilience as ability to withstand and 'bounce back' from major disruptive events, the course will consider resilience as an emergent attribute, and investigate some pre- and post-event approaches to resilience enhancement. The focus of the mathematical modeling techniques presented in this course will be on nonlinear dynamics. We will also discuss relevant variational optimization techniques that can be used to guide measures taken to enhance resilience. The course will include selected applications as case studies; examples include: savanna ecosystems, large installations, communities facing infectious diseases, preparation for and response to coastal storms, etc.

Prerequisite(s): Differential Equations.

Instructor(s): Korde

575.763 Nanotechnology and the Environment: Applications and Implications

This course explores the positives and negatives of nanotechnology: the benefits to use in commercial and environmental applications, as well as considering nanoparticles as an emerging environmental contaminant. The course will analyze nanotechnology through an interdisciplinary outlook for a life-cycle analysis. This analysis will begin with synthesis, manufacturing, unintentional releases, and disposal. We will consider ecological consequences and public health implications of the use of nanotechnology. Students will learn the science behind nanotechnology and how nanoparticle characteristics impact transport in the environment, including human exposure assessment, and a discussion of current measurement tools. Policies regulating nanotechnology and risk assessment will be addressed.

Instructor(s): Chalew

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 Environmental Health and Engineering. The proposal description and completed required forms must be submitted prior to registration for approval by the student's advisor and the program chair. A maximum of one independent project course may be applied toward the master's degree or post-master's certificate.

Instructor(s): Faculty, Department of Environmental Health and Engineering

APPLIED BIOMEDICAL ENGINEERING

585.207 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.

Course Note(s): Not for graduate credit.

Instructor(s): DiNovo-Collela, Potember

585.601 Physiology for Applied Biomedical Engineering I

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.

Instructor(s): Berman, Haase, Faculty

585.602 Physiology for Applied Biomedical Engineering II

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.

Instructor(s): Berman, Haase, Faculty

585.613 Medical Sensors and Devices

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

Instructor(s): Kraya, Thakor

585.615 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.

Prerequisite(s): Familiarity with multi-variable calculus, linear algebra, and ordinary differential equations.

Instructor(s): Rio

585.616 Principles of Medical Instrumentation and Devices

Biomedical sensors and devices are an integral part of modern medicine and they are becoming increasingly important with the growing need for objectivity and accessibility in diagnostics and therapeutics. The science and technology that goes into the plethora of sensors, although highly interdisciplinary, mainly derives from basic principles in physics and electrical engineering. This course will (re)introduce these principles and illustrate the application of these principles in a number of classes of medical sensors. It will also review some of the basic ideas and constraints that go into making of a medical device and finally touch upon a few nontechnical principles in applications of medical devices.

Course Note(s): Desirable background knowledge includes introductory level electrical engineering, circuit design, college level differential and integral calculus, and introductory human physiology.

Instructor(s): Maybhate

585.617 Rehabilitation Engineering

This course is an introduction to a field of engineering dedicated to improving the lives of people with disabilities. Rehabilitation engineering is the application of engineering analysis and design expertise to overcome disabilities and improve quality of life. A range of disabilities and assistive technologies will be investigated. The relationship between engineering innovation, the engineering design process, the human-technology interface, and the physical medicine and rehabilitation medical community will be explored. This course will require a semester long design project that addresses an unmet technological need. Students will choose a project with the instructor's approval. An engineering solution will be developed over the course of the semester through specification development, design reviews, and interacting with appropriate members of the medical community. There is a required visit to a local rehabilitation facility. For students who complete a software training module, access to a 3D printer will be available with assistance from an experienced designer.

Prerequisite(s): An undergraduate engineering degree or permission of the instructor.

Instructor(s): Drummond, Smith

585.619 Regulation of Medical Devices

Biomedical engineers are uniquely involved in many aspects of product development, from the inception of the idea to its delivery in the marketplace. This course will cover one major aspect of that process–the objectives and mechanisms of the FDA regulatory system governing the clinical use of medical devices in the United States, including regulatory pathways and device classification. Students will both analyze and discuss management of risk, and they will design controls related to cardiovascular, orthopedic, and neurological devices. By the end of the course, students will have a deep understanding of how the regulatory process is involved in every phase of medical device development.

Instructor(s): Drummond, Wyatt

585.625 Biomedical Engineering Practice and Innovation

This course will cover hands-on experimental and design work primarily in the areas of physiology, cell and tissue engineering, and biomedical instrumentation. In addition to teaching and allowing students to perform state-of-the art experimental techniques, this course will emphasize the business end of biomedical engineering innovation including identification of engineered needs and FDA regulation.

Prerequisite(s): 585.601 and 585.602 Physiology for Applied Biomedical Engineering I and II and 585.615 Mathematical Methods for Applied Biomedical Engineering or 535.641 Mathematical Methods for Engineers must be completed.

Course Note(s): This course is a combination online course and residency program at the Homewood campus.

Instructor(s): Drummond

585.703 Applied Medical Image Processing

Developments in medical image acquisition systems such as magnetic resonance imaging (MRI), computed tomography (CT), and ultrasound have resulted in a large number of clinical images with rich information regarding structure and function of different organs in the human body. A challenging task would be to extract clinically relevant information from the raw images that can be used to identify disease at an early stage or to monitor response to treatment. This course briefly introduces the underlying physical foundation of different image modalities followed by presentation of concepts and techniques that are used to process and extract information from medical images. Topics that are covered include medical image formats, enhancement, segmentation, registration, and visualization. MATLAB scripting language will be introduced and used to implement basic algorithms.

Prerequisite(s): 585.615 Mathematical Methods for Applied Biomedical Engineering or 535.641 Mathematical Methods for Engineers is required, or written permission from the instructor. 585.704 Principles of Medical Imaging is recommended. Preliminary knowledge of probability, linear algebra, and human anatomy is strongly recommended.

Instructor(s): Ardekani

585.704 Principles of Medical Imaging

With an emphasis on the physical principles behind modern medical imaging, this online course will cover topics such as mathematical and physical foundations of imaging; image construction and interpretation and image quality and image processing. Individual modules will cover various imaging modalities to provide an advanced understanding of the physics of the signal and its interaction with biological tissue; image formation or reconstruction; modality-specific issues for image quality; clinical applications; and biological effects and safety. Final modules will briefly touch on image analysis and describe applications for clinical diagnosis and/or treatment.

Prerequisite(s): 585.615 Mathematical Methods for Applied Biomedical Engineering or 535.641 Mathematical Methods for Engineers, or permission from the instructor. An introductory background in physics (electromagnetism) is recommended.

Instructor(s): Maybhate, Williams

585.708 Biomaterials

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

Instructor(s): Potember

585.709 Biomechanics of Cell and Stem Cells

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. The importance of the cell mechanical properties as indicators of the cell performance under normal and pathological conditions is emphasized. Major experimental techniques, such as micropipette aspiration, atomic force microscopy, and magnetic cytometry, to probe cell mechanical properties are presented. Linear elastic and viscoelastic models are introduced and applied to the interpretation of the mechanical experiments with endothelial cells and fibroblasts. Then the class discusses cell adhesion, spreading, and motility focusing on the experiments and models to estimate traction forces (stresses) produced by the cell. Finally, the effects of various mechanical factors (applied strains or forces, stiffness and viscoelastic properties, surface topography) on stem cell lineage commitment are discussed. Students also read and make presentations on original journal papers covering additional topics, which exposes them to the professional literature and hones their communication skills.

Instructor(s): Spector

585.710 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.

Instructor(s): Bryden, Potember

585.720 Orthopedic Biomechanics

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

Prerequisite(s): 585.601 and 585.602 Physiology for Applied Biomedical Engineering I and II (or equivalent).

Instructor(s): Dmitriev, Wyatt

585.724 Neural Prosthetics: Science, Technology, and Applications

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

Instructor(s): Wester, Faculty

585.726 Biomimetics in Biomedical Engineering

Biomimetics refers to human-made processes, substances, devices, or systems that imitate nature. This course focuses on substances prepared and engineered to meet biomedical uses. It is designed to provide students with: (1) an understanding of the biomimetic process of self-assembly, (2) an introduction to bioengineering biological materials and novel biomimetic materials that include forms and structures useful to bioprocesses, and (3) an understanding of how different instruments may be used for imaging, identification, and characterization of biological and biomimetic materials. Detailed knowledge of biological structure hierarchy is essential for most areas of biomedical engineering, and biological materials are becoming an increasingly important resource in creating new biomimetic materials that possess targeted biological structural and functional properties.

Instructor(s): Hamilton, White

585.729 Cell and Tissue Engineering

Cell and tissue engineering are dynamic and rapidly growing fields within biomedical engineering. This course will examine fundamental biological processes and medical engineering tools essential to regenerative medicine both at the single-cell and the whole-organism levels. Topics include stem cell engineering, cell–matrix and cell–scaffold interactions, cell–cell interactions and tissue morphogenesis, wound healing, and in vitro organogenesis.

Prerequisite(s): Knowledge of basic molecular and cellular biology, physiology, and math through ordinary differential equations is required.

Instructor(s): Drummond

585.732 Advanced Signal Processing for Biomedical Engineers

One of the defining topics for biomedical engineering, signal processing is playing an increasingly important role in modern times, mostly due to the ever-increasing popularity of portable, wearable, implantable, wireless, and miniature medical sensors/devices. The primary function of all the medical devices is acquisition and analysis of some kind of physiological data, often in a semi continuous real-time manner. From a medical stand point, the benefits that the devices offer pertain to complementing the physician in diagnosis, prognosis, and therapeutics. High-quality signal processing algorithm is a vital part of this process. On the research side, accurate signal processing plays a fundamentally important role in a medical device's validation and translation from bench to bedside. Mastering this important topic can equip the student with skills that can be immediately applied in real-life technological innovations. This new online course will primarily focus on advanced topics in signal processing, including linear and non-linear analysis of primary electro-physiological signals. Topics will include more traditional Auto-regressive Moving Average Analysis, spectral analysis, and singular value decomposition as well as advanced methods such as entropy computation, dimensionality estimation, state-space reconstruction, recurrence time analysis, parameter estimation, etc. Students will be challenged to write their own algorithms to reproduce select published research results.

Prerequisite(s): 585.615 Mathematical Methods for Applied Biomedical Engineering; 535.641 Mathematical Methods for Engineers; or written permission from the instructor. Knowledge of MATLAB is strongly recommended.

Instructor(s): Maybhate

585.734 Biophotonics

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

Instructor(s): Ramella-Roman, Sova

585.741 MR Imaging in Medicine

Advances in magnetic resonance Imaging (MRI) have resulted in developing techniques such as functional brain imaging, diffusion imaging, delayed contrast enhanced imaging, and tagged imaging. These techniques offer insights into the brain and cardiac structure and function. With increased availability of these techniques in clinical MRI machines, they are now entering clinical practice for the evaluation of neuro and cardiovascular disease. This course presents the underlying physical foundation of MRI, with a focus on more advanced techniques and their application in clinical research and practice. Topics that are covered include functional MRI, diffusion weighted imaging and techniques for mapping white matter fiber bundles, and cardiac cine and tagged imaging. Attention is also drawn to possible artifacts and pitfalls.

Prerequisite(s): 585.615 Mathematical Methods for Applied Biomedical Engineering or 535.641 Mathematical Methods for Engineers or a written permission from the instructor.

Instructor(s): Ardekani, Maybhate, Rio

585.747 Advances in Cardiovascular Medicine

This course is designed to provide in-depth instruction in cardiovascular physiology (building on the background provided in 585.601 Physiology for Applied Biomedical Engineering I) and cardiovascular responses to pathophysiological and environmental stressors. A quantitative, model-oriented approach to physiological responses is stressed. Students will research and present current advances in cardiovascular devices and procedures.

Prerequisite(s): 585.601 Physiology for Applied Biomedical Engineering I; 585.602 Physiology for Applied Biomedical Engineering II; and 585.625 Biomedical Engineering Practice and Innovation.

Instructor(s): Torgerson

585.751 Immunoengineering 💻

Immunoengineering is a quickly growing field where engineering principles are used to better understand the dynamics of the immune system and enhance the efficacy of current immunotherapeutics. This course will provide relevant background in our understanding of various immune responses including to pathogens, self, allergens, cancer, and biomaterials. An in-depth engineering perspective and approach will be taken in the analysis of these responses and the development of novel therapeutics. Topics include systems immunology, genetic engineering, nanotechnology, hydrogels, biomaterials, vaccines, cancer immunotherapy, autoimmunity, tissue engineering, stem cells, viruses, bacteria, etc.

Instructor(s): Hickey, Ben-Akiva

585.761 Bioentrenpreneurship 💻

Through lectures, discussion, and business planning, students will learn how to assess the feasibility of a life sciences startup venture. Over the course of the semester students will evaluate financial and market opportunities, build financial projections and author a business plan. Students will debate a wide range of important issues facing entrepreneurs. As a class, students will identify opportunity, assess the skills and talents of successful entrepreneurs, and investigate models and approaches that help leaders navigate the uncertainties of entrepreneurship and creating new life science ventures. Projects relating to imaging, instrumentation, or translational tissue engineering would be eligible for inclusion.

Instructor(s): Connolly

585.781 Frontiers in Neuroengineering 💻

Neuroscientists and neuroengineers are using state-of-the-art tools for understanding the mysteries of the brain. A suite of new approaches is allowing researchers to tap into the brain activity and to measure the electrical, molecular, cellular, and structural changes that underlie complex behaviors as well as neurological disorders such as Alzheimer's and Parkinson's disease. This technological burst, spurred by the recent BRAIN (Brain Research for Advancing Innovative Neurotechnologies) Initiative by the US government, affords a unique educational opportunity at Johns Hopkins-especially with the recently inaugurated Kavli Neuroscience Discovery Institute. This multi-instructor course will give students an opportunity to learn the latest advances in the field of neuroengineering from the best experts on campus who are currently contributing their pioneering research in this field.

Prerequisite(s): Written permission from the instructor is required. Completion of all required core courses, as well as the core courses for your chosen focus area, is strongly recommended.

Instructor(s): Gray Roncal, Maybhate, Scholl, Tsytsarev, Wester

585.783 Introduction to Brain-Computer Interfaces 💻

Recent advances in neural interfacing and neural imaging technology and the application of various signal processing methodologies have enabled us to better understand and then utilize brain activity for interacting with computers and other devices. In this course, we will explore these technologies and approaches for acquiring and then translating brain activity into useful information. We will also discuss the components of a brain-computer interface system, including invasive and non-invasive neural interfaces, the clinical and practical applications for a variety of users, and the ethical considerations of interfacing with the brain. Students will investigate the benefits and limitations of commonly used signal processing and machine learning methods (which include independent component analysis, Bayesian inference, dimensionality reduction, and information theoretic approaches), and then apply these methods on real neural data. We aim to equip students with the foundational knowledge and skills to pursue opportunities in the emerging field of brain-computer interfacing.

Prerequisite(s): 585.615 Mathematical Methods for Applied Biomedical Engineering; 535.641 Mathematical Methods for Engineers; or a written permission from the instructor. 585.732 Advanced Signal Processing for Biomedical Engineers and a good knowledge of MATLAB are strongly recommended.

Instructor(s): Benz, Maybhate, Pohlmeyer, Wester

585.800 Independent Study I 💻

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. The applied biomedical engineering project proposal form must be completed prior to registration.

Prerequisite(s): Permission of the instructor required.

Instructor(s): Maybhate

585.801 Independent Study II 💻

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

Prerequisite(s): Permission of the instructor required.

Instructor(s): Maybhate

ENGINEERING MANAGEMENT AND TECHNICAL MANAGEMENT

595.627 Advanced Concepts in Agile Technical Management

How do highly skilled technical managers and system engineers like you address complex projects with high levels of uncertainty requiring continuous innovation and adaptation? This course will provide you the expertise needed to lead a highly skilled, cross-functional technical workforce capable of successfully executing these most demanding projects. You will participate using an experienced-based style of team-based learning implementing advanced leadership principles designed to deliver game-changing value to your customer. You will learn to apply a blend of agile, lean and design-thinking methods to technical leadership within a complex, evolving system engineering environment while still achieving a set of product requirements and design elements meeting schedule and budget allocations. You will gain critical insight into criteria necessary to assess the relevance of these advanced methods to specific projects and organizational culture. This course is offered through a virtual-live delivery environment where you attend biweekly online sessions in the Zoom application executing an unfolding project simulation from within an intact team cohort.

Instructor(s): Cameron, Menner

595.660 Planning and Managing Projects VL

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; 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 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.

Course Note(s): The format for this course is either online or a mixed online/live environment called Virtual Live. For the Virtual Live format, weekly lectures are provided either online or live (and recorded) on a predesignated day/time, with students/instructors joining in person or from any location via personal computer. Students can also choose to participate in person, in a classroom, at the predesignated day/time. Contact the instructors for additional information. (Formerly 595.600 Introduction to Project Management.)

Instructor(s): Ackerman, Blank, Buchanan, Caporaletti, Collins, Holub, Kedia, Lubic, Simpson, Tarchalski

595.661 Technical Group Management

This course covers the general functions and responsibilities of a technical group supervisor. Topics include functions of a technical group in an R&D or engineering organization; primary responsibilities of a group supervisor; interactions with management, support organizations, and project organizations; organization of projects in group structure; development of work costs and schedules; progress monitoring and reporting; introduction to personnel management leadership, motivation, evaluation, and professional growth; reaction to critical problems; technical leadership; and planning for the future. Students assume the roles of technical group supervisors in a high-technology organization. They address typical problems in delegating responsibilities, staffing new projects, dealing with project managers, and handling conflicts and priorities.

Instructor(s): Blank, Collins, Fletcher, Holub, Horne-Jahrling, Miller

595.663 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.

Instructor(s): Collins, Dever, Harris, Holub, Regan

595.664 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; earned value performance measurement; analysis of project performance measures; integrated project planning; new product development considerations; enterprise information systems applications; and risk management.

Instructor(s): Collins, Dever, Holub, Liggett, Shinn

595.665 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.

Instructor(s): Bjerkaas, Caporaletti, Collins, Fletcher, Horne-Jahrling, Johnson, Michelson, Phillips

595.666 Financial and Contract Management

This course is an introduction to financial and contract management for technical managers. Topics include financial and management accounting (including elementary accounting principles, assets, liabilities, and stockholders' equity); direct and indirect costs, revenues, and profits; indices to financial position; use of financial reports; return on investment, net present value; internal rate of return; and financial management (including cash and funds flow statements). An introduction to the principles of contract formation is presented highlighting the distinctive characteristics of contracting with the federal government as well as the team concept for effective contracting and the role of the program manager as a key team member. Subcontract management, competitive negotiation techniques, contract financing, and cost reimbursement are also included. Case studies supplement theoretical discussions.

Instructor(s): Blank, Collins, Dever, Kohr, Liggett, Lubic, Wyant

595.731 Business Law for Technical Professionals

This course addresses legal issues commonly encountered by technical professionals, best practices in identifying and mitigating legal risks, and strategies to avoid costly legal errors and to recognize when professional legal advice is necessary. The course will acquaint students with various areas of the law that can interact to affect a single business transaction and will provide students with legal reasoning skills that can be applied in a technical business environment. Topics include the legal environment of business, contract basics, effective contract negotiations, breach of contract and remedies, intellectual property rights, licensing and technology transfer, protecting confidential and proprietary business information, employment law, Internet law, corporate policies, business ethics, export control regulations, and an overview of the American court system.

Instructor(s): Henderson, Moore, Oostburg Sanz

595.740 Assuring Success of Aerospace Programs

Technical managers, systems engineers, lead engineers, and mission assurance professionals will benefit from this course, which focuses on the leadership of system safety and mission assurance activities throughout the life cycle of a project to achieve mission success. This advanced course provides crucial lessons learned and proven best practices that technical managers need to know to be successful. The integrated application of mission assurance and systems engineering principles and techniques is presented in the context of aerospace programs and is also applicable to other advanced technology research and development programs. Students discuss critical risk-based decision making required from system concept definition and degree auditing through design, procurement, manufacturing, integration and test, launch, and mission operations. Experiences shared by senior aerospace leaders and extensive case studies of actual mishaps explore quality management topics relevant to aircraft, missiles, launch vehicles, satellites, and space vehicles. The course addresses contemporary leadership themes, government policies, and aerospace industry trends in mission assurance requirements, organizational structure, knowledge sharing and communication, independent review, audit, and assessment. Mission assurance disciplines covered include risk management, system safety, reliability engineering, software assurance, supply chain management, parts and materials, configuration management, requirements verification and validation, non-conformance, and anomaly tracking and trending.

Instructor(s): Day, Dever, Phillips

595.742 Foundations of Quality Management VL

This course addresses quality management topics and applications vital to steering leadership and business process approaches for various organizations. Course discussions range from the history and development of modern quality programs to the latest in quality and business management, strategic planning, productivity improvement tools, techniques, and the implementation of quality initiatives needed to be successful in today's highly dynamic and competitive global market. Advanced topics related to the principles and application of quality methodologies are presented such as the impact of leadership and corporate culture on quality and the importance of quality during the proposal and contract review process. Students will understand the elements and implementation strategies of quality assurance tools and systems, including benchmarking, process control, quality measurement, supplier quality management, and auditing. Current applications and strategies for implementing effective quality management are introduced including lean manufacturing philosophies, Deming's PDCA cycle, Kaizen continuous improvement processes, and risk management. The course also covers a comprehensive and practical understanding of the implementation of quality management systems such as ISO 9001. As a result of the significant impact that software and system safety now have on today's organizations, sessions dedicated to both topics are also included.

Course Note(s): The format for this course is a mixed online/live environment called Virtual Live. Weekly lectures are provided live (and recorded) on a predesignated day/time, with students/instructors joining from any location via personal computer. Students can also choose to participate in person, in a classroom, at the predesignated day/time. Contact the instructors for additional information.

Instructor(s): Mitchell, Seifert

595.762 Management of Technical Organizations

The course reviews challenges in the management of high-technology organizations at the senior technical management level. Using organizational behavior theories and practices in conjunction with critical thinking, the student will explore topics that include: senior technical manager roles and responsibilities in relation to ethics, leadership style, motivation, and performance of top management teams. The student will also evaluate leading change, communications and organizational relationships, and the potential effects organizational design and processes play in influencing individual behaviors by themselves or within a group. The student will assume the role of a senior technical manager dealing with typical organizational behavior problems in rapidly changing environments.

Prerequisite(s): 595.663 Technical Personnel Management and 595.665 Communications in Technical Organizations

Instructor(s): Collins, Harris, Michelson, Regan

595.766 Advanced Technology VL

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 and culminates in a term paper on a new or emerging technology area.

Prerequisite(s): 595.660 Planning and Managing Projects or 645.662 Introduction to Systems Engineering.

Course Note(s): The format for this course is a mixed online/live environment called Virtual Live. Weekly lectures are provided live (and recorded) on a predesignated day/time, with students/instructors joining from any location via personal computer. Contact the instructors for additional information.

Instructor(s): McLoughlin, Theodori

595.781 Executive Technical Leadership VL

This course explores the roles and responsibilities of executive technical leaders within the context of a strategic framework. Examples of technical executive positions are VP/Director of R&D or Engineering, VP/Director of Manufacturing, Chief Technical Officer (CTO), Chief Information Officer (CIO), Technical Director (Government), and large program Chief Engineer. The course introduces topics relevant to technical executives, from technical strategy development to tactical operations, such as metrics and measurements for leading technical teams within the context of larger organizations. The concepts in the course are reinforced using associated case studies and a team project and are further fortified by practicing or retired technical executive guest interviews delivering practical career experiences related to the topics presented in the course. The format of this course is very different from other Engineering or Technical Management courses. Lectures are offered asynchronously online with a required weekly seminar-type virtual-live discussion. Student participation in the weekly seminar-type virtual-live sessions, mid-course team presentation, semester-end capstone presentation, and executive roundtable are required. Students will be evaluated on their application of the principles presented in the course, critical thinking applied to the issues posed in the case study, and teamwork as assessed by both the instructors and their peer students.

Prerequisite(s): 595.660 Planning and Managing Projects.

Course Note(s): The format for this course is a mixed online/live environment called Virtual Live. For the Virtual Live format, weekly lectures are provided asynchronous online for students to view in advance of the weekly seminar sessions. The weekly seminar sessions are held at a predesignated day/time, with students/instructors joining in real-time web conference from any location via personal computer. Contact the instructors for additional information. The course also includes one

Saturday session in the Baltimore, MD, area at the end of the semester. In-person participation with your team is expected. An alternative individual assignment is available for students not able to attend Capstone Day in person. The Saturday session consists of student teams presenting their capstone technical executive strategic issues, actions, and execution plans built around the case study evolution throughout the course. A roundtable discussion will also be held where students have the opportunity to ask probing questions of visiting executives as part of the Capstone Day experience.

Instructor(s): Blank, Collins, McLoughlin, Tarchalski

595.793 Applied Innovation for Technical Professionals

"Agile", "crowdfunding", "lean", "open innovation"—the nature of innovation is radically changing in the 21st century. How can technical professionals thrive amidst the new models, tools and processes that are creating faster cycles of disruption? This course will address challenges faced by technical managers in creating and sustaining innovation across a wide range of organizations and environments: from government labs to Fortune 1,000 companies to small businesses and startups. Students will learn the many issues involved in turning creative ideas into a product or service and how to gain support for projects, demonstrate value of the innovation, scale to a profitable venture, and sustain the innovation through successive competitive life cycles. Students will also learn about the challenges and techniques for sustaining innovative cultures in large organizations and how to foster "intrepreneurship"—the concept of creating innovations within the processes and cultures of an already established organization. Case studies and interviews with experienced senior managers will provide students with the latest real-world insights.

Prerequisite(s): 595.660 Planning and Managing Projects.

Course Note(s): The format for this course is a mixed online/live environment called Virtual Live. For the Virtual Live format, weekly lectures are provided live online (and recorded) on a predesignated day/time, with students/instructors joining remotely from any location via personal computer. Contact the instructors for additional information. Lectures are offered asynchronously online with a required weekly seminar-type virtual-live participation. Lectures and videos will be available asynchronously online. The weekly seminar-type presentations/discussions are attended via web meeting. This course includes a weekend session to be attended via web conference. The practicum may also include working sessions on the team project to be attended via web conference. Please refer to the course schedule for updated information.

Instructor(s): Geertsen, McLoughlin

595.802 Directed Studies in Technical Management

In this course qualified students are permitted to investigate possible research fields or to pursue problems of interest through reading or nonlaboratory study under the direction of faculty members.

Prerequisite(s): The Independent Study/Project Form (ep.jhu.edu/student-forms) must be completed and approved prior to registration.

Course Note(s): This course is open only to candidates in the Master of Science in Technical Management program.

Instructor(s): Blank, Collins

COMPUTER SCIENCE

605.101 Introduction to Python

Not for a letter grade. Offered pass/fail only. This is a six-week course. The withdrawal deadline is the end of the fourth week. Students must pass each module to pass the course.

Course Note(s): Not for graduate credit. This course does not satisfy any admission requirements.

Instructor(s): Non-facilitated

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(s): One year of college mathematics.

Course Note(s): Not for graduate credit. A programming methodology course is needed for admission to the Computer Science, Cybersecurity, Data Science, or Information Systems Engineering program. Students who lack this prerequisite can fulfill admission requirements by completing this course with a grade of B– or better.

Instructor(s): Balk, Deal, DeMasco, Ferguson, Jockel, 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. (Not for Graduate credit.)

Prerequisite(s): One year of college mathematics. 605.201 Introduction to Programming Using Java or equivalent.

Course Note(s): Not for graduate credit. A course in data structures is needed for admission to the Computer Science, Cybersecurity, or Data Science program. Students who lack this prerequisite can fulfill admission requirements by completing this course with a grade of B– or better. A course in data structures is conditionally required for admission to the Information Systems Engineering program. Students who lack this prerequisite can satisfy it by completing this course with a grade of B– or better before taking any course that requires it.

Instructor(s): Chlan, R. Cost, Guven, Kann, Rajasekaran, Shah

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.

Prerequisite(s): Calculus is recommended.

Course Note(s): Not for graduate credit. A mathematics course beyond one year of calculus is needed for admission to the Computer Science, Cybersecurity, or Data Science program. A course in either calculus or discrete mathematics is needed for admission to the Information Systems Engineering program. Students who lack this prerequisite can fulfill admission requirements by completing this course with a grade of B– or better.

Instructor(s): Chlan, Farmer

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(s): 605.202 - Data Structures is recommended.

Course Note(s): Not for graduate credit. A course in computer organization is needed for admission to the Computer Science or Cybersecurity program. Students who lack this prerequisite can fulfill admission requirements by completing this course with a grade of B– or better.

Instructor(s): Kann, Kovba, Snyder

605.205 Molecular Biology for Computer Scientists

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

Course Note(s): Not for graduate credit. Several courses in the Bioinformatics track of Computer Science require background in Molecular Biology. Students can fulfill this requirement by completing this course with a grade of B- or better.

Instructor(s): H. Cost

605.601 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.

Course Note(s): The required foundation courses may be taken in any order but must be taken before other courses in the degree.

Instructor(s): Coffman, DeMasco, Garonzik, Hazra, Lindberg, Schappelle, Wichmann

605.602 Secure Software Analysis and Design

This course prepares students to successfully engineer secure software systems by addressing critical security challenges across the entire software development life cycle. Students will learn the practical skills for building secure software from the ground up through hands-on labs and exercises. Key topical areas addressed include security in software requirements, design, and development. Common security pitfalls are highlighted and examined as well as the tools and techniques for identifying and eliminating the security vulnerabilities. Security considerations in Mobile code development are also addressed. Parameterized refinement methods and transduction techniques based on mathematical-based proofs are presented as a means of verifying the correctness of code and modifications to code as well as to validate conformance with functional requirements. Software protection techniques such as code obfuscation and water-marking are explored.

Instructor(s): Hazra

605.604 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. The course material embraces the C++11 language standard with numerous examples demonstrating the benefits of C++11.

Prerequisite(s): Knowledge of Java or C++.

Instructor(s): Demasco, Ferguson, Pierson

605.606 Programming with Domain-Specific Languages

Domain-specific languages (DSLs) are little languages you write that look and feel like a spoken way to specify data or write code. You can use them for input and output, incorporating the jargon and nomenclature of your subject-matter experts (SMEs), as well as inside your own code to make it more expressive and fluent, and often simpler. You can use them as part of your build process to generate hundreds of classes full of otherwise tedious and error-prone boilerplate code from a small specification in a consistent manner. In this course, we'll design and implement several types of DSLs. We'll write code to edit and import data, allowing SMEs more natural-feeling access to your software. We'll create APIs in multiple programming languages to make it easier and more secure for others to use your libraries. We'll generate code to improve productivity and reliability in your own software.

Course Note(s): Examples and assignments in this class will be done in several programming languages. We assume a high comfort level with Java and the ability to adapt to new languages quickly.

Instructor(s): Stanchfield

605.607 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, Kanban, Dynamic Systems Development Method, and Feature-Driven Development. These methods promote teamwork, rich concise communication, and the frequent delivery of running, tested systems containing the highest-priority stakeholder features. Agile methods are contrasted with common workplace practices and traditional methods such as Waterfall, CMMI, and PMI/PMBOK. Examples of agile adoption in industry are discussed. Assignments and projects are designed to help students apply agile principles and practices in their own professional context. Additional subthemes in the course include enterprise agility, team dynamics, collaboration, software quality, and metrics for reporting progress.

Prerequisite(s): 605.202 Data Structures.

Instructor(s): Menner

605.608 Software Project Management

This course describes the key aspects of a software project. It begins with the job description of a software manager and then addresses those topics germane to successful software development management, including organizing the software development team; interfacing with other engineering organizations (systems engineering, quality assurance, configuration management, and test engineering); assessing development standards; selecting the best approach and tailoring the process model; estimating software cost and schedule; planning and documenting the plan; staffing the effort; managing 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.

Prerequisite(s): Three to five years technical work experience is recommended.

Instructor(s): Winston

605.609 DevOps Software Development

"DevOps" evokes an agile software development approach in an operational environment. Modern technologies, particularly cloud and big data analytics, often embrace DevOps methods.

The term was first used to indicate "agile infrastructure." Recently, it has often referred to quick adoption of emerging technology and subsequent integration into production. This course gathers the latest publications to examine the tools for source code control, automated build, automated test, and automated deployment, some of which will be selected by the students in an operational rhythm of Continuous Integration (CI) and Continuous Deployment (CD). This course discusses the basic concepts of DevOps, including its philosophy, workflow, monitoring methods, and tools. Topics include: concepts and vision for DevOps, release/deployment pipelines, automated testing, monitoring production, task evaluation, skills assessment, and tool selection. Students will apply these concepts to see how they can be best implemented to automate development, test, and release practices. Students will work in teams to build functional working models of realized DevOps.

Prerequisite(s): Prior experience in software development in any language is required. Familiarity with software design, development, and architecture techniques is recommended.

Instructor(s): Garonzik, Young

605.611 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.

Course Note(s): The required foundation courses may be taken in any order but must be taken before other courses in the degree.

Instructor(s): Kann, Malcom, Osborn, Shell, Whisnant

605.612 Operating Systems

The theory and concepts related to operating system design are presented from both developer and user perspectives. Core concepts covered include process management, memory management, file systems, I/O system management including device drivers, distributed systems, and multi-user concepts including protection and security. Process management discussions focus on threads, scheduling, and synchronization. Memory management topics include paging, segmentation, and virtual memory. Students will examine how these concepts are realized in several current open-source operating systems, including Linux. Students will complete several assignments that require the design and implementation of operating system programs using a high-level language.

Instructor(s): Deal, Noble

605.614 System Development in the UNIX Environment

This course describes how to implement software systems in a UNIX (POSIX-compliant) operating system environment. Students will discuss and learn the complexities, methodologies, and tools in the development of large systems that contain multiple programs. Topics include an overview of the UNIX system and its general-purpose tools, advanced makefile usage, UNIX system calls, UNIX process management, threads, and basic and advanced interprocess communication. Additional topics include source code configuration control, Perl, and debugging techniques.

Prerequisite(s): Familiarity with UNIX, experience with C++ or C.

Instructor(s): Barrett, Noble

605.615 Compiler Design with LLVM

The components of a compiler appear in every software application that handles input from an external source. This course shows how the components of a compiler are built and how they fit together to extract meaning from the input information. It shows how the data flows through the components to become useful to applications containing the compiler's components. Students will learn to use the LLVM tools to build a compiler that can produce machine code to target almost any platform including the Java Virtual Machine. By the end of the course, students will have developed a complete compiler that can do this for a subset of the C++ programming language.

Instructor(s): Ferguson, Shell

605.616 Multiprocessor Architecture and Programming

This course addresses how to utilize the increasing hardware capabilities of multiprocessor computer architecture's high-performance computing platforms for software development. The famous Moore's Law is still alive, although it is now realized from increasing the number of CPU cores instead of increasing CPU clock speed. This course describes the differences between single-core and multi-core systems and addresses the impact of these differences in multiprocessor computer architectures and operating systems. Parallel programming techniques to increase program performance by leveraging the multiprocessor system, including multi-core architectures, will be introduced. Additional topics include program performance analysis and tuning, task parallelism, synchronization strategies, shared memory access and data structures, and task partition techniques. The course encourages hands-on experience with projects selected by the student.

Instructor(s): Zheng

605.617 Introduction to GPU Programming

This course will teach the fundamentals needed to utilize the ever-increasing power of the GPUs housed in the video cards attached to our computers. For years, this capability was limited to the processing of graphics data for presentation to the user. With the CUDA and OpenCL frameworks, programmers can develop applications that harness this power directly to search, modify, and quickly analyze large amounts of various types of data. Students will be introduced to core concurrent programming principles, along with the specific hardware and software considerations of these frameworks. In addition, students will learn canonical algorithms used to perform high-precision mathematics and data transformations. Class time will be split between lectures and hands-on exercises. There will be two individual projects in both CUDA and OpenCL programming, which will allow students to independently choose demonstrable goals, develop software to achieve those goals, and present the results of their efforts.

Instructor(s): Pascale

605.620 Algorithms for Bioinformatics

This follow-on course to data structures (e.g., 605.202 Data Structures) provides a survey of computer algorithms, examines fundamental techniques in algorithm design and analysis, and develops problem-solving skills required in all programs of study involving computer science. Topics include advanced data structures (red-black and 2-3-4 trees, union-find), algorithm analysis and computational complexity (recurrence relations, big-O notation, introduction to NP-completeness), sorting and searching, design paradigms (divide and conquer, greedy heuristic, dynamic programming), and graph algorithms (depth-first and breadth-first search, minimum spanning trees). Advanced topics are selected from among the following: multi-threaded algorithms, matrix operations, linear programming, string matching, computational geometry, and approximation algorithms. The course will draw on applications from Bioinformatics.

Prerequisite(s): 605.202 Data Structures or equivalent, and 605.201 Introduction to Programming Using Java or equivalent. 605.203 Discrete Mathematics or equivalent is recommended.

Course Note(s): This course does not satisfy the foundation course requirement for Data Science, Computer Science, or Cybersecurity. Students can only earn credit for one of 605.620, 605.621, or 685.621.

Instructor(s): Chlan, Dillon

605.621 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(s): 605.202 Data Structures or equivalent. 605.203 Discrete Mathematics or equivalent is recommended.

Course Note(s): The required foundation courses may be taken in any order but must be taken before other courses in the degree. Students can only earn credit for one of 605.620, 605.621, or 685.621.

Instructor(s): Boon, Chen, Gearhart, Guven, Lew, Rodriguez, Sadowsky, Sheppard

605.622 Computational Signal Processing

This course introduces computational aspects of signal processing, specifically algorithms for processing digital signals, methods for the design and analysis of signal processing algorithms, architectures for signal processing systems, and areas of application. Topics include signal analysis (signal definition, time and frequency domains, sampling and digitizing, noise and error), systems for signal processing (filters and nonfilters, correlation, adaptation), and algorithms and architectures (fast Fourier transforms, fast convolution, digital filtering, interpolation and resampling, digital signal processors, function evaluation, and computational complexity). Areas of application include communication systems, speech signal processing, and digital media.

Prerequisite(s): Knowledge of complex numbers and linear algebra.

Instructor(s): Sadowsky

605.623 Introduction to Enumerative Combinatorics

The most basic question in mathematics is "How many?". Counting problems arise in diverse areas including discrete probability and the analysis of the run time of algorithms. In this course we present methods for answering enumeration questions exactly and approximately. Topics include fundamental counting problems (lists, sets, partitions, and so forth), combinatorial proof, inclusion-exclusion, ordinary and exponential generating functions, group-theory methods, and asymptotics. Examples are drawn from areas such as graph theory and block designs. After completing this course students will be practiced in applying the fundamental functions (such as factorial, binomial coefficients, Stirling numbers) and techniques for solving a wide variety of exact enumeration problems as well as notation and methods for approximate counting (asymptotic equality, big-oh and little-oh notation, etc.).

Prerequisite(s): Linear algebra

Course Note(s): This course is the same as 625.617 Introduction to Enumerative Combinatorics.

Instructor(s): Scheinerman

605.624 Logic: Systems, Semantics, and Models

The use of predicate logic for modeling information systems is widespread and growing. Knowledge representation, for example, has long been important in artificial intelligence applications and is now emerging as a critical component of semantic web applications. Similarly, predicate logic is the basis for ontologies and inferential knowledge bases that support systems managing "big data" using graph databases and triple stores. This course teaches the fundamentals of propositional and predicate logic, with an emphasis on semantics. We start with a fast-paced introduction or a refresher on propositional and predicate logic, to serve as a stepping stone to more advanced topics in logics with application to computer science. 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 (e.g., "Agent A knows that Agent B knows fact X"), and has been key to the development of IBM's Watson and RDF/OWL. Finally, dynamic logic is introduced to manage potentially inconsistent systems, such as may arise in merging disparate databases or in combining diagnostic models of related systems.

Course Note(s): This course may be counted toward a three-course track in Database Systems and Knowledge Management.

Instructor(s): Faculty

605.625 Probabilistic Graphical Models

This course introduces the fundamentals behind the mathematical and logical framework of graphical models. These models are used in many areas of machine learning and arise in numerous challenging and intriguing problems in data analysis, mathematics, and computer science. For example, the "big data" world frequently uses graphical models to solve problems. While the framework introduced in this course will be largely mathematical, we will also present algorithms and connections to problem domains. The course will begin with the fundamentals of probability theory and will then move into Bayesian networks, undirected graphical models, template-based models, and Gaussian networks. The nature of inference and learning on the graphical structures will be covered, with explorations of complexity, conditioning, clique trees, and optimization. The course will use weekly problem sets and a term project to encourage mastery of the fundamentals of this emerging area.

Prerequisite(s): Graduate course in probability and statistics (such as 625.603 Statistical Methods and Data Analysis).

Course Note(s): This course is the same as 625.692 Probabilistic Graphical Models.

Instructor(s): Woolf

605.626 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(s): Familiarity with Fourier transforms.

Instructor(s): Caban

605.627 Computational Photography

Computational photography is an emerging research area at the intersection of computer graphics, image processing, and computer vision. As digital cameras become more popular and collections of images continue to grow, we've seen a surge in interest in effective ways to enhance photography and produce more realistic images through the use of computational techniques. Computational photography overcomes the limitations of conventional photography by analyzing, manipulating, combining, searching, and synthesizing images to produce more compelling, rich, and vivid visual representations of the world. This course will introduce the fundamental concepts of image processing, computer vision, and computer graphics, as well as their applications to photography. Topics include image formation, filtering, blending, and completion techniques. In addition, the course will discuss different image analysis and rendering techniques including texture analysis, morphing, and non-photorealistic rendering.

Instructor(s): Caban

605.628 Applied Topology

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

Prerequisite(s): Multivariate calculus, linear algebra and matrix theory (e.g., Matrix Theory 625.609), and an undergraduate-level course in probability and statistics.

Course Note(s): This course is the same as 625.687 Applied Topology.

Instructor(s): Boswell, Sorokina

605.629 Programming Languages

This course compares and contrasts a wide variety of features of at least twelve programming languages, including programming language history; formal methods of describing syntax and semantics; names, binding, type checking, and scopes; data types; expressions and assignment statements; statement-level control structures; design and implementation of subprograms; exception handling; and support for object-oriented programming. Students will also learn and write four-week projects in three programming languages (e.g., Python, Perl, and C#).

Instructor(s): Guven

605.631 Statistical Methods for Computer Science

Statistical methods are the foundation for data science, artificial intelligence, and much of the field of computer science. Topics include probability, random variables, regression, gradient search, Bayesian methods, graphical methods, and exponential random graph models. Student will have the foundation to excel in future courses in machine learning, data science, algorithms, and more. Practice exercises will develop proficiency in the R programming language.

Instructor(s): Johnson and McCulloh

605.632 Graph Analytics

Graphs are a flexible data structure that facilitates fusion of disparate data sets. Applications of graphs have shown steady growth with the development of Internet, cyber, and social networks, presenting large graphs for which analysis remains a challenging problem. This course introduces algorithms and techniques to address large-scale graph analytics. It will blend graph analytics theory, hands-on development of graph analytics algorithms, as well as processing approaches that support the analytics. We will start by introducing graphs, their properties, and example applications, including necessary background on probability and linear algebra. Statistical properties of random and scale-free graphs will be introduced. Graph analytic methods, including centrality measures, graph clustering, partitioning, link inference, and dynamic graph processes such as diffusion, contagion, and opinion formation will be covered. Application of graph analytics to high-dimensional data analysis and data clustering will be discussed. Students will use standard graph interfaces as well as linear algebra-based methods to analyze graphs. Parallelization of analytics to handle larger-scale graphs will be discussed. Students will identify and apply suitable algorithms and analysis techniques to a variety of graph analytics problems, as well as gain experience setting up and solving these problems. There will be hands-on programming assignments.

Instructor(s): Savkli

605.633 Social Media Analytics

Today an immense social media landscape is being fueled by new applications, growth of devices (e.g., Smartphones and devices), and human appetite for online engagement. With a myriad of applications and users, significant interest exists in the obvious question, "How does one better understand human behavior in these communities to improve the design and monitoring of these communities?" To address this question a multidisciplinary approach that combines social network analysis (SNA), natural language processing, and data analytics is required. This course combines all these topics to address contemporary topics such as marketing, population influence, etc. There will be several small projects.

Prerequisite(s): Knowledge of Python or R; matrix algebra.

Instructor(s): McCulloh and Piorkowski

605.634 Crowdsourcing and Human Computation

Crowdsourcing and human computation reverses the typical approach to computing. Rather than using computers to conduct computation that is too difficult for a human, many humans are used to conduct computation that is too difficult for a computer. This course explores computer science topics that lie at the intersection of data science and social psychology. Topics include crowdsourcing, social media, social network analysis, games, gamification, ubiquitous computing, and computer-supported cooperative work. Laboratory exercises will involve hands-on data collection and analysis to include Mechanical Turk and require programming in R or Python depending on student preference/proficiency.

Instructor(s): McCulloh and Merritt

605.635 Cloud Computing

Cloud computing helps organizations realize cost savings and efficiencies without spending capital resources up front, while modernizing and expanding their IT capabilities. Cloud-based infrastructure is rapidly scalable, secure, and accessible over the Internet—you pay only for what you use. So, enterprises worldwide, big and small, are moving toward cloud-computing solutions for meeting their computing needs, including the use of Infrastructure as a Service (IaaS) and Platform as a Service (PaaS). We have also seen a fundamental shift from shrink-wrapped software to Software as a Service (SaaS) in data centers across the globe. Moreover, providers such as Amazon, Google, and Microsoft have opened their datacenters to third parties by providing low-level services such as storage, computation, and bandwidth. This trend is creating the need for a new kind of enterprise architect, developer, QA, and operational professional—someone who understands and can effectively use cloud-computing technologies and solutions. In this course, we discuss critical cloud topics such as cloud service models (IaaS, PaaS, SaaS); virtualization and how it relates to cloud; elastic computing; cloud storage; cloud networking; cloud databases; cloud security; and architecting, developing, and deploying apps in the cloud. The format of this course will be a mix of lectures, and hands-on demos. Upon completing this course, students will have a deeper understanding of what cloud computing is and the various technologies that make up cloud computing, along with hands-on experience working with a major cloud provider.

Prerequisite(s): 605.202 Data Structures.

Instructor(s): Joshi and Shyamsunder

605.641 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.

Prerequisite(s): 605.202 Data Structures.

Instructor(s): Kung

605.643 Linked Data and the Semantic Web

The World Wide Web Consortium (W3C) is endeavoring to create standards and technology that support a distributed "Web of data." Collectively, these advances allow the systems we develop to work and interact more effectively, through the use of XML-based languages, and information on how various tags relate to real-world objects and concepts. This course covers a range of Semantic Web technologies, including RDF (Resource Description Framework - a model for data interchange) and OWL (Web Ontology Language), as well as domain-specific standards and ontologies (formal specifications of how to represent objects and concepts). Representative applications of RDF, OWL, and ontologies to various problems will be discussed. Students will apply course concepts to an in-depth project in an area of personal or professional interest.

Prerequisite(s): 605.202 Data Structures.

Course Note(s): This course may be counted toward a three-course track in Bioinformatics.

Instructor(s): R. Cost

605.644 XML Design Paradigms

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

Prerequisite(s): 605.681 Principles of Enterprise Web Development or equivalent Java experience.

Instructor(s): Chittargi

605.645 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 investigate a wide variety of approaches to artificial intelligence 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 have the opportunity to explore both the philosophical and practical issues of artificial intelligence during the course of the class.

Instructor(s): Butcher

605.646 Natural Language Processing

This course surveys the principal difficulties of working with written language data, the fundamental techniques that are used in processing natural language, and the core applications of NLP technology. Topics covered in the course include language modeling, text classification, labeling sequential data (tagging), parsing, information extraction, question answering, machine translation, and semantics. The dominant paradigm in contemporary NLP uses supervised machine learning to train models based on either probability theory or deep neural networks. Both formalisms will be covered. A practical approach is emphasized in the course, and students will write programs and use open source toolkits and to solve a variety of problems.

Prerequisite(s): There are no formal prerequisites, though having taken any of 605.649 Introduction to Machine Learning, 605.744 Information Retrieval, or 605.645 Artificial Intelligence is helpful.

Instructor(s): McNamee and Mayfield

605.647 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.

Prerequisite(s): Multivariate calculus and linear algebra.

Course Note(s): This course is the same as 625.638 Neural Networks.

Instructor(s): Fleischer

605.649 Introduction to Machine Learning

Analyzing large data sets ("Big Data"), is an increasingly important skill set. One of the disciplines being relied upon for such analysis is machine learning. In this course, we will approach machine learning from a practitioner's perspective. We will examine the issues that impact our ability to learn good models (e.g., the curse of dimensionality, the bias-variance dilemma, and no free lunch). We will then examine a variety of approaches to learning models, covering the spectrum from unsupervised to supervised learning, as well as parametric versus non-parametric methods. Students will explore and implement several learning methods, including logistic regression, Bayesian classification, decision trees, and feed-forward neural networks, and will incorporate strategies for addressing the issues impacting performance (e.g., regularization, clustering, and dimensionality reduction). In addition, students will engage in online discussions, focusing on the key questions in developing learning systems. At the end of this course, students will be able to implement and apply a variety of machine learning methods to real-world problems, as well as be able to assess the performance of these algorithms on different types of data sets.

Instructor(s): Sheppard

605.651 Principles of Bioinformatics

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; phylogenic tree construction; and clustering algorithms.

Prerequisite(s): Familiarity with probability and statistics; working knowledge of Java, C++, C, Perl, MATLAB or Python; 605.205 Molecular Biology for Computer Scientists or a course in molecular biology; and a course in either cell biology or biochemistry.

Instructor(s): Qie

605.652 Biological Databases and Database Tools

The sequencing of thousands of genomes, including those related to disease states, interest in proteomics, epigenetics, and variation have resulted in an explosive growth in the number of biological databases, as well as the need to develop new databases to handle the diverse new content being generated. The course focuses on the design of biological databases and examines issues such as those related to data modeling, heterogeneity, interoperability, evidence, and tool integration. It also surveys a wide range of biological databases and their access tools and enables students to develop proficiency in their use. Databases introduced include genome and sequence databases such as GenBank and Ensembl, as well as protein databases such as PDB and UniProt. Databases related to RNA, sequence variation, pathways and interactions, metagenomics, and epigenomics are also presented. Tools for accessing and manipulating data from databases such as BLAST, genome browsers, multiple sequence alignment, gene finding, and protein tools are reviewed. The programming language Perl is introduced, along with the use of Perl in obtaining data via web services and in storing data in an SQLite database. Students will use Perl, biological databases, and database tools to complete homework assignments. They will also design a database and will write code in the language of their choice to create their own database as a course project.

Prerequisite(s): (For JHEP Students) 605.205 Molecular Biology for Computer Scientists or 410.634 Practical Computer Concepts for Bioinformatics or equivalent; 605.641 Principles of Database Systems or equivalent; 605.202 Data Structures and 605.201 Introduction to Programming Using Java.

Instructor(s): Hobbs

605.653 Computational Genomics

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

Prerequisite(s): 605.205 Molecular Biology for Computer Scientists or equivalent and familiarity with probability and statistics.

Instructor(s): Ermolaeva

605.656 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.

Prerequisite(s): 605.205 Molecular Biology for Computer Scientists or equivalent.

605.657 Statistics for Bioinformatics

This course provides an introduction to the statistical methods commonly used in bioinformatics and biological research. The course briefly reviews basic probability and statistics including events, conditional probabilities, Bayes; theorem, random variables, probability distributions, and hypothesis testing and then proceeds to topics more specific to bioinformatics research, including Markov chains, hidden Markov models, Bayesian statistics, and Bayesian networks. Students will learn the principles behind these statistical methods and how they can be applied to analyze biological sequences and data.

Prerequisite(s): 605.205 Molecular Biology for Computer Scientists or equivalent, and 410.645 Biostatistics or another statistics course.

Instructor(s): Ermolaeva

605.662 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(s): Experience with data collection/analysis in data-intensive fields or background in computer graphics (e.g., 605.667 Computer Graphics) is recommended.

Instructor(s): Caban, Chlan

605.667 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(s): Familiarity with linear algebra.

Instructor(s): Nesbitt

605.671 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 asynchronously 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 correction techniques; BSC and HDLC data link layer protocols; Huffman, MNP5, and V.42bis data compression algorithms; circuit, message, packet, and cell switching techniques; public key and symmetric encryption algorithms, authentication, digital signature, and message digest techniques, secure e-mail, PGP, and TSL/SSL security algorithms; Ethernet, Wi-Fi, Optical, and IP networks; reliability and availability; and queuing analysis network performance techniques.

Instructor(s): Nieporent, Smith

605.672 Computer Network Architectures and Protocols

This course provides a detailed examination of the conceptual framework for modeling communications between processes residing on independent hosts, as well as the rules and procedures that mediate the exchange of information between two communication processes. The Open Systems Interconnection Reference Model (OSIRM) is presented and compared with TCP/IP and other network architectures. The service definitions and protocols for implementing each of the seven layers of the Reference Model using both OSI and TCP/IP protocols are analyzed in detail. Internetworking among heterogeneous subnets is described in terms of addressing and routing, and techniques for identifying different protocol suites sent over the subnets are explained. The protocol header encoding rules are examined, and techniques for parsing protocol headers are analyzed. The application layer sub-architecture for providing common application services is described, and interoperability techniques for implementing multiprotocol internets are presented. Topics include layering, encapsulation, SAPs, and PDUs; sliding window protocols, flow and error control; virtual circuits and datagrams; routing and congestion control algorithms; 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; OSI transitioning tools; multiprotocol networks; and encapsulation, tunneling, and convergence techniques.

Prerequisite(s): 605.671 Principles of Data Communications Networks.

Instructor(s): Nieporent

605.673 High-Speed Internet Architecture, Technologies, and Applications

The Internet has experienced unprecedented growth especially since the 1990s and is continuing to evolve in terms of the information transfer speeds and infrastructure capacities in order to accommodate the growing number of users. The demand for bandwidth-both wired and wireless-and innovative new bandwidth-intensive services is soaring. The use of high-definition video, real-time collaboration, e-commerce, social networking, and other multimedia Web applications is becoming increasingly important to individual users and businesses. The use of mobile broadband and file-sharing applications is rising sharply. Advances in research applications and the evolution to cloud networking are also causing bandwidth pressure on existing networks. This course will provide an in-depth understanding of the Internet architecture and underlying technologies and applications that address the challenges summarized above and provide services to users at high availability, reliability, and flexibility in a cost-effective manner. Specific topics to be discussed in this course include high-speed Internet requirements analysis, Internet architecture and protocols, convergence of mobile and terrestrial networks, high-speed LAN/WAN options and configurations, emerging and future switching and transmission technologies, and network virtualization. The course will also cover unique challenges to management and security of the high-speed Internets and how they are addressed. Other topics include emerging technologies and future trends.

Prerequisite(s): 605.202 Data Structures; 605.671 Principles of Data Communications Networks.

Instructor(s): Krishnan

605.674 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.

Prerequisite(s): 605.671 Principles of Data Communications Networks, or 605.614 System Development in the UNIX Environment .

Instructor(s): Noble

605.675 Protocol Design and Simulation

This course covers the formal design, specification, and validation of computer and network protocols. Design, implementation, and verification of protocols will be illustrated using the latest simulation tools, such as OPNET and NS2. Protocol examples include the latest wired and wireless networks, such as the IEEE 802.X family, as well as protocols in VoIP, Web 2.0, and network security. The course focuses on protocol specification, structured protocol design, protocol models, and protocol validation. Students will gain hands-on experience using simulation tools to design, validate, and assess protocols.

Prerequisite(s): 605.671 Principles of Data Communications Networks or equivalent.

Instructor(s): Zheng

605.677 Internetworking with TCP/IP I

This course investigates the underlying technology of the Internet. The presentation begins with a survey of distributed applications operating over the Internet, including the Web, electronic mail, VoIP, instant messaging, file transfers and peer-to-peer file sharing. The course investigates the details of the Internet architecture and the TCP/IP protocol suite, covering the protocols that provide communications services to end systems and the management and control protocols that create the Internet from disparate underlying networks and technologies. Communications-related protocols analyzed in detail include the foundational Internet Protocol (IP), the connection-oriented reliable Transmission Control Protocol (TCP), the connectionless User Datagram Protocol (UDP) and the Real-Time Protocol (RTP) for streaming media. To allow the student to understand the control and management of the Internet, the course analyzes protocols that support naming (DNS), addressing and configuration (DHCP), management (SNMP) and the dynamic IP routing protocols RIP, OSPF and BGP.

Prerequisite(s): 605.202 Data Structures; 605.671 Principles of Data Communications Networks.

Instructor(s): Boules, Watkins

605.678 Next Generation Mobile Networks with 5G

The primary focus of this course is to introduce the next generation mobile networks including both Cellular and WLAN technologies in great detail, discuss various types of IP-based mobility protocols, namely Mobile-IP, Mobile IPv6, ProxyMIPv6, SIP-mobility, Cellular IP and systems optimization techniques to support seamless handover during Inter RAT handover (e.g., 4G, WLAN). This course will briefly introduce the principles of cellular communications system and will then move on to describe the evolution of different generation of cellular systems including 2G, 3G, 4G, and 5G as being defined in 3GPP. At the same time it will discuss IEEE WLAN standards as developed by IEEE 802 working group including 802.11 (a, b, g, n) and 802.11 (ax, ay, ac). The Media Independent Handover standard IEEE 802.21 (e.g., integrating WLAN and 3G/4G cellular networks to provide session/service continuity) is also introduced. This course will describe the 4G Long Term Evolution (LTE) in detail covering its various components, namely Evolved UMTS Terrestrial Radio Access Network (E-UTRAN), EPC (Evolved Packet Network) and IMS (IP Multimedia Subsystem) and all the associated interfaces and protocols. The topics include protocol architecture, bearer management, signaling, radio resource control (RRC), packet data convergence protocol (PDCP), radio link control (RLC), and MAC. In addition, the role of universal subscriber identity module (USIM), eNodeB, mobility management entity (MME), serving gateway (S-GW), packet data network gateway (P-GW), and home subscription server (HSS) as well as the call flow across these various nodes will be presented. LTE security will be covered as well. The voice over LTE (VoLTE), self-organizing network (SON), LTE-direct, and LTE-Advanced [including coordinated multipoint (CoMP), carrier aggregation, and Inter-cell interference coordination (ICIC)] will be presented. The course will present various deployment use cases and experimental results from the open-source testbeds.

The course will describe the current efforts on 5G evolution and will touch upon various 5G pillars, namely SDN (Software Defined Networking), Network Function Virtualization, Cloud RAN, Network Slicing, Mobile Edge Cloud, and Security. The course will also highlight various standards activities within 3GPP, IEEE, IETF, NGMN, and ITU and will introduce some research problems for future study in the mobility area.

Prerequisite(s): 605.202 Data Structures; 605.671 Principles of Data Communications Networks.

Instructor(s): Dutta

605.681 Principles of Enterprise Web Development

This course examines three major topics in the development of applications for the World Wide Web. The first is website development using HTML and related standards. The second is the implementation of client-side applications using the Java programming language, including user interface development, asynchronously 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).

Prerequisite(s): 605.202 Data Structures.

Instructor(s): Chittargi, Evans, Spiegel

605.682 Web Application Development with Java

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

Prerequisite(s): 605.681 Principles of Enterprise Web Development or equivalent Java experience.

Course Note(s): Formerly 605.682 Web Application Development with Servlets and JavaServer Pages (JSP).

Instructor(s): Chittargi, Shyamsunder

605.684 Agile Development with Ruby on Rails

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

Prerequisite(s): 605.681 Principles of Enterprise Web Development or equivalent; 605.202 Data Structures.

Instructor(s): Hazins

605.686 Mobile Application Development for the Android Platform

This project-oriented course will investigate application development for the Android mobile platform. We will look at techniques for building applications that adapt to the ways in which mobile apps differ from traditional desktop or web-based apps, including constrained resources, small screen sizes, varying display resolutions, intermittent network connectivity, specialized sensors, and security restrictions. We will explore best practices for making mobile applications flexible: using XML-based layouts, networking via NFC and Wi-Fi, determining device location and orientation, deploying applications, gracefully handling shutdowns and restarts to the application, embedding web components in applications, showing maps with the Google Maps plug-in, and storing local data with SQLite.

Prerequisite(s): Expertise in simple SQL, Java and basic APIs, including callbacks, threads, XML, lists, and maps..

Course Note(s): Students should already be very comfortable with Java. Students will be provided links to download free tools for building and testing Android apps. Note that Android emulators may run quite slowly on some machines; physical Android devices are strongly recommended for this course.

Instructor(s): Stanchfield

605.687 Mobile Application Development for the iOS Platform

This project-oriented course will investigate application development on iOS platforms. First, we will cover the main language for iOS, Swift, a new language to which Apple is transitioning for both iOS and OS X development, along with tools such as Xcode, Interface Builder, Instruments, and Swift Playgrounds. Second, we will discuss the aspects of creating an application: the application life cycle, user experience and data presentation, user interface elements, and application performance. Then, we will discuss the application frameworks that the iOS SDK provides: CoreData, SpriteKit, MapKit, and Notifications, to name just a few. Finally, we will prepare your app for deployment, considering localization and internationalization, accessibility, and iTunes Connect. By the end of the class, students will be able to use Xcode, implement the Model-View-Controller paradigm, use Protocols and Delegates, construct a user interface, store and retrieve data on the network, interact with the OS or other applications, distinguish between the various iOS frameworks, and explain the App publication process.

Prerequisite(s): 605.201 Introduction to Programming Using Java or equivalent Java or Objective C experience.

Course Note(s): Access to a Mac running at least OS X 10.12 is required for this class. Development tools can be downloaded for free from the Mac App Store. Additional hardware (iPhones, iPods, iPads) is not necessary, but if you plan on fully deploying your app then testing on additional hardware is highly recommended. *THIS REQUIREMENT IS SUBJECT TO CHANGE*

Instructor(s): Steele

605.701 Software Systems Engineering

Software Systems Engineering applies engineering principles and the system view to the software development process. The course focuses on the engineering of complex systems that have a strong software component. This course is based on the philosophy that the key to engineering a good software system lies just as much in the process that is followed as in the purely technical regime. The course will show how good a software development process is and how to make a software process better by studying successful techniques that have been employed to produce correct software systems within budget. Topics are explored in a sequence designed to reflect the way one would choose to implement process improvements. These topics include steps to initiate process change, methods to establish control over the software process, ways to specify the development process, methods for quantitative process control, and how to focus on problem prevention. Students will prepare term projects.

Prerequisite(s): 605.202 Data Structures; one software engineering course beyond 605.601 Foundations of Software Engineering.

Instructor(s): Donaldson, Siegel, White

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(s): 605.601 Foundations of Software Engineering and 605.704 Object-Oriented Analysis and Design or equivalent experience are highly recommended.

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

Instructor(s): Demasco and Schappelle

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 that could have been avoided. Specific techniques of risk analysis, hazard analysis, fault tolerance, and safety tradeoffs within the software engineering paradigm are discussed.

Prerequisite(s): 605.202 Data Structures.

Instructor(s): Almes, Gieszl

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(s): 605.604 Object-Oriented Programming with C++ or permission of instructor.

Instructor(s): Lindberg

605.708 Tools and Techniques of Software Project Management

This course examines tools and techniques used to lead software-intensive programs. Techniques for RFP analysis and proposal development are explored, and techniques of size estimation (function points, feature points, and lines-of-code estimation) and the use of models such as COCOMO to convert size to effort and schedule are described. In addition, conversion of estimated effort to dollars and the effects of fringe, overhead, skill mix profiles, and staffing profiles on total dollar cost are explained. Moreover, techniques for estimating effort and planning the COTS intensive development programs are described, and tools and techniques for measuring process maturity and process efficiency (e.g., CMMi, Lean, Six Sigma, and Kaizen) are addressed. The course also investigates the formation and management of virtual teams, as well as techniques that can be used to ensure success in this environment. Finally, the course addresses topics that require collaboration between the project manager and human resources, such as personnel retention strategies, managing unsatisfactory performance, and formal mentoring programs.

Prerequisite(s): Three to five years technical work experience is recommended.

Instructor(s): Hazra

605.709 Seminar in Software Engineering

This course examines the underlying concepts and latest topics in software engineering. Potential topics include use of effective open-source software development techniques such as agile methods, automated code generation, testing strategies, development tools and environments, patterns, metrics in the development process, successful teamwork, and training aspects of CMMI. Each student will select and report on a software engineering topic, independently research a topic, and prepare a paper describing a major software engineering issue. The course is taught using a seminar format in which significant portions of the class period are set aside for students to lead and actively participate in discussions.

Prerequisite(s): One software engineering course beyond 605.601 Foundations of Software Engineering or permission of the instructor.

605.713 Robotics

This course introduces the fundamentals of robot design and development with an emphasis on autonomy. Robot design, navigation, obstacle avoidance, and artificial intelligence will be discussed. Topics covered in robot design include robot structure, kinematics and dynamics, the mathematics of robot control (multiple coordinate systems and transformations), and designing for autonomy. Navigation topics include path planning, position estimation, sensors (e.g., vision, ultrasonics, and lasers), and sensor fusion. Obstacle avoidance topics include obstacle characterization, object detection, sensors and sensor fusion. Topics to be discussed in artificial intelligence include learning, reasoning, and decision making. Students will deepen their understanding through several assignments and the term-long robot development project.

Instructor(s): Lapin

605.715 Software Development for Real-Time Embedded Systems

This course examines the hardware and software technologies behind real-time, embedded computer systems. From smart kitchen appliances to sophisticated flight control for airliners, embedded computers play an important role in our everyday lives. Hardware topics include microcomputers and support devices (e.g., flash, ROM, DMA, timers, clocks, A/D, and D/A), as well as common applications (e.g., servo and stepper motor control, automotive sensors, and voice processing). Software topics focus on unique aspects of embedded programming and include interrupts, real-time control, communication, common design patterns, and special test considerations. The course also explores the unique tools that are used to develop and test embedded systems. Labs, beginning with using Bare Metal and Free RTOS on Arduino for simple devices and culminating with using Linux on Raspberry-Pi for Quad-Copter flight control, are developed.

Instructor(s): Ferguson

605.716 Modeling and Simulation of Complex Systems

This multi-disciplinary 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 organism, an ecological system, the economy, fluids or strongly-coupled solids). The subject is interdisciplinary with foundations in mathematics, nonlinear science, numerical simulations and statistical physics. The course begins with an overview of complex systems, followed by modeling techniques based on nonlinear differential equations, networks, and stochastic models. Simulations are conducted via numerical calculus, analog circuits, Monte Carlo methods, and cellular automata. In the course we will model, program, and analyze a wide variety of complex systems, including dynamical and chaotic systems, cellular automata, and iterated functions. By defining and iterating an individual course project throughout the term, students will gain hands-on experience and understanding of complex systems that arise from combinations of elementary rules. Students will be able to define, solve, and plot systems of linear and non-linear systems of differential equations and model various complex systems important in applications of population biology, epidemiology, circuit theory, fluid mechanics, and statistical physics.

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

Course Note(s): This course may be counted toward a three-course concentration in Bioinformatics.

Instructor(s): Weisman, Wiley

605.721 Design and Analysis of Algorithms

In this follow-on course to 605.621 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.

Prerequisite(s): 605.621 Foundations of Algorithms or equivalent; 605.203 Discrete Mathematics or equivalent.

Instructor(s): Boon

605.724 Applied Game Theory

In many organizations in the private and the public sectors, there is a need to support complex decisions that include a game-theoretic aspect. These decisions impact activities ranging from tactical to strategic, and play out in a number of problems, including monitoring and management of ongoing operations, the dynamics of organizational relationships in the competitive environment, and military force planning. This course extends treatment of game theoretic concepts and constructs, and explores their implementation and application, highlighting key issues such as decision space exploration and analysis, visualization, and the creation and use of models for specific domains. Students will have the opportunity to design a course project based on their area of professional or personal interest.

Instructor(s): R. Cost

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 multitasking computers. Queuing theory provides a rich and useful set of mathematical models for the analysis and design of service process for which there is contention for shared resources. This course explores both theory and application of fundamental and advanced models in this field. Fundamental models include single- and multiple-server Markov queues, bulk arrival and bulk service processes, and priority queues. Applications emphasize communication networks and computer operations, but may include examples from transportation, manufacturing, and the service industry. Advanced topics may vary.

Prerequisite(s): Multivariate calculus and a graduate course in probability and statistics such as 625.603 Statistical Methods and Data Analysis or equivalent.

Course Note(s): This course is the same as 625.734 Queuing Theory with Applications to Computer Science.

Instructor(s): Nickel

605.726 Game Theory

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

Prerequisite(s): Multivariate calculus, linear algebra and matrix theory (e.g., 625.609 Matrix Theory), and a course in probability and statistics (such as 625.603 Statistical Methods and Data Analysis).

Course Note(s): This course is the same as 625.741 Game Theory.

Instructor(s): Castello

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; proximity searching, 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; dimension reduction in data; and robot motion planning around polygon obstacles. Applications to such areas as computer graphics, big data analytics and pattern recognition, geometric databases, numerical taxonomy, and robotics will be addressed. The course covers theory to the extent that it aids in understanding how the algorithms work. Emphasis is placed on algorithm design and implementation. Programming projects are an important part of the coursework.

Prerequisite(s): Foundations of algorithms. Some familiarity with linear algebra.

Instructor(s): Sadowsky

605.728 Quantum Computation

Scalable quantum computers aren't here yet. But recent progress suggests they may be on their way, and that it is now time to start planning for their potential impact: NSA announced in 2015 a shift in focus from elliptic curve to quantum resistant cryptography, and NIST has initiated a large-scale study of post-quantum cryptography. This course provides an introduction to quantum computation for computer scientists: the focus is on algorithms rather than physical devices, and familiarity with quantum mechanics (or any physics at all) is not a prerequisite. Instead, pertinent aspects of the quantum mechanics formalism are developed as needed in class. The course begins with an introduction to the QM formalism. It then develops the abstract model of a quantum computer, and discusses how quantum computers enable us to achieve, for some problems, a significant speedup (in some cases an exponential speedup) over any known classical algorithm. This discussion provides the basis for a detailed examination of quantum integer factoring, quantum search, and other quantum algorithms. The course also explores quantum error correction, quantum teleportation, and quantum cryptography. It concludes with a glimpse at what the cryptographic landscape will look like in a world with quantum computers. Required work includes problem sets and a research project.

Prerequisite(s): Some familiarity with linear algebra and with the design and analysis of algorithms.

Instructor(s): Zaret

605.729 Formal Methods

Formal verification of a program is the mathematical proof that it does what is expected of it. The 21st century has seen a vast worldwide interest in formal methods. Four journals (Automated Reasoning, Logic and Algebraic Programming, Formalized Mathematics, and Science of Computer Programming) and over a dozen yearly conferences, each of which has been held at least since 2000, are specifically devoted to these matters. Centers of ongoing formal methods research include Argonne, Berkeley, Bialystok (Poland), Cambridge, Clemson, HP, INRIA, Iowa State, Karlsruhe, Lausanne, Microsoft, MITRE, Munich, NYU, Penn, Praxis, and SRI. Methods have been developed for Java (JML), Ada (SPARC), C#, C, and Eiffel (Spec#), Haskell, Ocaml, and Scheme (Coq), Pascal (Sunrise), Modula-3 (ESC), and a number of special-purpose languages. This course is an introduction to this vast world of formal methods. Our concern will be the formal verification of the widest possible variety of programming language features and techniques. Each student will carry out an investigation of one or another of the existing formal verification systems, applying it to a program of the student's choice.

Instructor(s): Guven

605.731 Cloud Computing Security

The promise of significant cost savings and inherent flexibility of resources are an impetus for the adoption of cloud computing by many organizations. Cloud computing also introduces privacy and security risks that are not traditionally present in a siloed data center. This course focuses on these security concerns and countermeasures for a cloud environment. An overview of cloud computing and virtualization, the critical technology underpinning cloud computing, provides the necessary background for these threats. Additional topics vary but may include access control, identity management, denial of service, account and service hijacking, secure APIs, malware, forensics, regulatory compliance, trustworthy computing, and secure computing in the cloud. This course follows a seminar-style format where students are expected to lead class discussions and write a publication-quality paper as part of a course project.

Instructor(s): Coffman

605.741 Large-Scale Database Systems

This course investigates the theory and practice of modern large-scale database systems. Large-scale approaches include distributed relational databases; data warehouses; and the Hadoop ecosystem (Hadoop, Accumulo, and the Mahout machine learning libraries). Topics discussed include data design and architecture; database security, integrity, query processing, query optimization, transaction management, concurrency control, and fault tolerance; and query formulation, algorithms, and cloud analytics. At the end of the course, students will understand the principles of several common large-scale data systems including their architecture, performance, and costs. Students will also gain a sense of which approach is recommended for different circumstances.

Prerequisite(s): 605.202 Data Structures; 605.641 Principles of Database Systems or equivalent. Familiarity with "big-O" concepts and notation is recommended.

Instructor(s): Silberberg

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.

Prerequisite(s): 605.202 Data Structures.

Instructor(s): McNamee

605.745 Reasoning Under Uncertainty

This course is concerned with the problems of inference and decision making under uncertainty. It develops the theoretical basis for a number of different approaches and explores sample applications. The course discusses foundational issues in probability and statistics, including the meaning of probability statement, and the necessity of a rational agent acting in accord with probability theory. We will look at possible generalizations of Bayesian probability, including Dempster-Shafer theory. Next, we will develop algorithms for Bayesian networks—graphical probabilistic models—for exact and approximate inference and consider several application areas. Finally, the course will examine the problem of making optimal decisions under uncertainty. We will explore the conceptual foundations of decision theory and then consider influence diagrams, which are graphical models extending Bayesian networks to the domain of decision analysis. As time permits, we will also look at Bayesian games and Markov decision processes. Pertinent background in probability and theoretical computer science is developed as needed in the course.

Instructor(s): M. Johnson

605.746 Advanced Machine Learning

This course focuses on recent advances in machine learning and on developing skills for performing research to advance the state of knowledge in machine learning. The material integrates multiple ideas from basic machine learning and assumes familiarity with concepts such as inductive bias, the bias-variance trade-off, the curse of dimensionality, and no free lunch. Topics range from determining appropriate data representations and models for learning, understanding different algorithms for knowledge and model discovery, and using sound theoretical and experimental techniques in assessing learning performance. Specific approaches discussed cover nonparametric and parametric learning; supervised, unsupervised, and semi-supervised learning; graphical models; ensemble methods; and reinforcement learning. Topics will be discussed in the context of research reported in the literature within the previous three years. Students will participate in seminar discussions and will present the results of their individual research project.

Prerequisite(s): 605.649 Introduction to Machine Learning; multivariate calculus, linear algebra, probability and statistics, discrete mathematics.

Instructor(s): 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.

Instructor(s): Sheppard

605.748 Semantic Natural Language Processing

This course introduces the fundamental concepts underlying knowledge representation, semantics, and pragmatics in natural language processing. Students will gain an in-depth understanding of the techniques central to computational semantics and discourse for processing linguistic information. The course examines semantic NLP models and algorithms using both the traditional symbolic and the more recent statistical approaches. The course also covers the development of modern NLP systems capable of carrying out dialogue and conversation.

Prerequisite(s): 605.645 Artificial Intelligence or equivalent

Course Note(s): This course and 605.646 Natural Language Processing can be taken independently of each other.

605.751 Algorithms for Structural Bioinformatics

This course is an interdisciplinary approach to the concepts, principals, computational methods and algorithms used in structural bioinformatics. It focuses on the fundamental aspects of structural biology along with computational methods and algorithms for studying protein folding, structure prediction and analysis. Algorithms for the prediction and annotation of protein secondary and tertiary structure and for structure-structure comparison will be studied in depth. We will also show how such algorithms and methods can be adapted for use with nucleic acids structure prediction and analysis. Students will apply various software tools and structure-visualization software to protein structure prediction and structure-structure comparison.

Prerequisite(s): 605.205 Molecular Biology for Computer Scientists or equivalent. 605.661 Principles of Bioinformatics is recommended.

Instructor(s): Qie

605.754 Analysis of Gene Expression and High-Content Biological Data

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

Prerequisite(s): 605.205 Molecular Biology for Computer Scientists or equivalent or a prior course in Bioinformatics, a course in probability and statistics, and ability to program in a high-level language.

Course Note(s): 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.

605.755 Systems Biology

Systems biology is the study of complex biological systems using theoretical, mathematical, and computational tools and concepts. The advent of genomics, big data, and high-powered computing is allowing better understanding and elucidation of these systems. Central to systems biology is the development of computational models, based on sound statistics, which incorporate biological structures and networks, and can be informed and tested, with data on multiple scales. In this class, students will learn to develop and use different types of models of complex biological systems and how to test and perturb them. Students will learn basic biological system components and dynamics, as well as the data formats, sources, and modeling tools required to interrogate them. Tools will be used relating to functional genomics, evolution, biochemical systems, and cell biology. Students will utilize a model they have developed and available data from public repositories to investigate both a discovery-based project and a hypothesis-based project.

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

Instructor(s): Bradburne

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.

Course Note(s): A student may not receive credit for both 605.759 and 605.802 Independent Study in Computer Science II.

605.767 Applied Computer Graphics

This course examines advanced rendering topics in computer graphics. The course focuses on the mathematics and theory behind 3D graphics rendering. Topics include 3D surface representations including fractal geometry methods; visible surface detection and hidden surface removal; and surface rendering methods with discussion of lighting models, color theory, texturing, and ray tracing. Laboratory exercises provide practical application of these concepts. The course also includes a survey of graphics rendering applications (animation, modeling and simulation, and realistic rendering) and software. Students perform laboratory exercises using the C++ programming language.

Prerequisite(s): 605.667 Computer Graphics or familiarity with three-dimensional viewing and modeling transformations.

Instructor(s): Nesbitt

605.771 Wired and Wireless Local and Metropolitan Area Networks

This course provides a detailed examination of wired and wireless local and metropolitan area network (LAN and MAN) 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 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 (Wi-Fi) 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(s): 605.202 Data Structures; 605.671 Principles of Data Communications Networks or 635.611 Principles of Network Engineering.

Instructor(s): Nieporent

605.772 Network and Security Management

Information transfer speeds and infrastructure capacities must continue to evolve to support not only traditional voice and data but also multimedia services such as high-definition video, real-time collaboration, e-commerce, and social networking. While services are provided across terrestrial and mobile networks transparently to users, new technologies such as cloud computing efficiently make the services available to users irrespective of their geographic locations. In this rapidly evolving technological environment, network and security management (NSM) is the key to providing network access and connectivity, ensuring high availability of applications and services, and assuring users of the reliability and security of their transported information. Network Management (NM) encompasses all the activities, methods, operational procedures, tools, communications interfaces, protocols, and human resources pertaining to the operation, administration, maintenance, provisioning, and growth planning of communications networks. Security Management (SM) pertains to monitoring and control of security services and mechanisms including identification, authentication, authorization, access control, confidentiality, intrusion detection, correction, and prevention in order to protect the communications network infrastructure and services. NSM includes setting, monitoring, and maintaining certain performance metrics to ensure high performance levels and quality of service (QoS) to the users, along with support for infrastructure architecture and security planning, design, and implementation. This course examines NSM standards, technologies, tools, industry best practices, and case studies, NSM areas that can be automated through expert systems, current issues, and future trends to adapt to emerging and evolving Internet technologies. Specific Internet and telecommunications standards discussed in depth in this course include SNMPv1, SNMPv2, SNMPv3, RMON, and OSI. Students will apply the standards, architectures, tools, and techniques learned in the course, as well as research state-of-the-art technologies in a team project.

Prerequisite(s): 605.771 Wired and Wireless Local and Metropolitan Area Networks, or 605.672 Computer Network Architectures and Protocols, or 605.677 Internetworking with TCP/IP I, or 635.611 Principles of Network Engineering.

Instructor(s): Krishnan

605.775 Optical Networking Technology

The Internet has hundreds of millions of users, is growing rapidly, and continues to evolve to accommodate an increasing number of voice, data, video, and imagery applications with diverse service requirements. Internet Protocol (IP) is the primary unifying protocol converging these applications and services over the Internet. The Internet's evolution has been accompanied by exponentially growing traffic volume on the network infrastructure. Optical networks are ideally suited to carry such large volumes of traffic, and the next generation of optical networks will be optimized for delivery of IP services while providing capacity in the range of terabits per second in a scalable and flexible way to support services such as voice over IP (VoIP) and IP television (IPTV). This course provides an in-depth understanding of existing and emerging optical network technologies. Specific topics covered include basics of fiber optic communications, SONET, DWDM, optical Ethernet, FTTB, FTTH, 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(s): 605.673 High-Speed Internet Architecture, Technologies, and Applications or permission of the instructor.

Instructor(s): Krishnan

605.776 Fourth Generation Wireless Communications: WiMAX and LTE

This course compares the WiMAX and LTE fourth-generation (4G) technologies and their performance. An overview of the IEEE 802.16 standards (802.16d/e/j/m/n/p) and WiMAX Forum (Fixed WiMAX vs. Mobile WiMAX, Interoperability certification and Core network) is presented along with the 3GPP standards for LTE and LTE-Advanced as well as LTE network architecture. The physical layer (OFDM, OFDMA, Scalable OFDMA, SC-FDMA, FDD/TDD, and DL/UL channels), reference signal/pilot, 2D resources, and multi-antenna techniques (diversity, MIMO, and beam forming) for both technologies is introduced. For WiMAX, the MAC, call flow, 2D resource map, QoS, and scheduling are presented. For LTE, both control plane and data plane protocols for Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) and Evolved Packet Core (EPC) are presented. The topics include protocol architecture, bearer management, signaling, radio resource control (RRC), packet data convergence protocol (PDCP), radio link control (RLC), and MAC. In addition, the role of universal subscriber identity module (USIM), eNodeB, mobility management entity (MME), serving gateway (S-GW), packet data network gateway (P-GW), and home subscription server (HSS) as well as the call flow across these various nodes will be presented. The 2D resource grid along with QoS and scheduling will be explained in detail. The voice over LTE (VoLTE), self-organizing network (SON), LTE-direct, and LTE-Advanced [including coordinated multipoint (CoMP), carrier aggregation, and Intercell interference coordination (ICIC)] will be presented. Finally, spectrum considerations as well as the concept of white space and dynamic spectrum access (DSA) will be discussed.

Prerequisite(s): 605.202 Data Structures; 605.671 Principles of Data Communications Networks or 635.611 Principles of Network Engineering and another course in the Data Communications and Networking track.

Instructor(s): Shyy

605.777 Internetworking with TCP/IP II

This course builds on the foundation established in 605.677, 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, CIP, MPOA, IP Switching, Tag Switching, MPLS, IP Multicast, IGMP, Reliable Musticast, Multicast Routing Protocols, IP Mobility Home Agents and Foreign Agents, Message Tunneling, Proxy and Gratuitous ARP, VPN Tunneling, 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(s): 605.202 Data Structures; 605.677 Internetworking with TCP/IP I.

Instructor(s): 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 and strategies to address the issues. In this course, students will gain understanding of how to adapt an IP packet network, which is basically designed for data, to provide wide-area voice communications. Topics include telephony fundamentals, Voice Over IP concepts, adapting IP networks to support voice, H.323 and SIP signaling protocols, QoS issues in IP networks, IETF standards, and network management.

Prerequisite(s): 605.202 Data Structures; 605.677 Internetworking with TCP/IP I or 605.673 High-Speed Internet Architecture, Technologies, and Applications, or significant Internet technology-related work experience.

Instructor(s): Krishnan

605.779 Network Design and Performance Analysis

Networking services are a staple of our daily life. Different types of networks surround us all day long. This ubiquitous networking, thanks to smartphones and tablet computers, gives us the convenience of information at our fingertips. The right network architecture provides the fundamental support for network services, such as the products from Facebook, Google, Apple, etc. This course covers the details of network design and the design process. Starting from requirement specifications, a detail flow analysis is introduced. Examples of different network architecture designs, both in wireline and wireless, will be discussed, including mobile Ad Hoc network (MANET), mesh network, 4G cellular networks, wide area network (WAN), cloud networks, and advanced software define networking (SDN). Performance analyses and network security aspects are considered at every step of the design. Secured architecture covers Virtual Private Network (VPN) and Transport Layer Security (TLS)-based systems, with details on firewall and intrusion detection configurations. The course encourages hands-on projects selected from real network system problems.

Instructor(s): Zheng

605.784 Enterprise Computing with Java

This comprehensive course explores a variety of modern Java frameworks and technologies that can be used for developing mission-critical complex enterprise applications. The emphasis is on use of the latest Java EE platform, its set of underlying specifications, designing and developing server-side application components. Students will learn through having hands-on experience in building multi-tier based distributed enterprise applications, comparing and using a variety of Java EE design patterns, and a rich set of server-side components and technologies, web-enabled by modern design practices and communication protocols. Students will review Java Database Connectivity (JDBC) API, and will implement a data access tier to a relational database using Java Persistence API (JPA) and variety of data access patterns; They will implement synchronous and asynchronous server-side business logic using stateless and stateful session EJBs, message-driven beans and EJB Timer service; integrate server-side logic with the web-tier components using legacy server-side and more modern RESTful API approaches that include JSON and other data formats. Other critical Java EE infrastructure services will be discussed, including the Java Naming and Directory Interface (JNDI), the Java Message Service (JMS), the Java Transaction (JTA) API, and Java EE security. Students will review and discuss Spring framework and inversion of control, as well as some alternative solutions for developing and deploying enterprise applications.

Students will design and implement several significant programming projects and deploy them to a Java EE environment that they will manage.

Prerequisite(s): 605.202 Data Structures; 605.681 Principles of Enterprise Web Development or equivalent.

Course Note(s): Students will be assumed to already have strong Java skills and to be comfortable with IDEs.

Instructor(s): L. Felikson, Shyamsunder, Stafford

605.785 Web Services with SOAP and REST: Frameworks, Processes, and Applications

Web services is a technology, process, and software paradigm to extend the web from an infrastructure that provides services for humans to one that supports business integration over the web. This course presents concepts, features, and architectural models of web services from three perspectives: framework, process, and applications. Students will study three emerging standard protocols: Simple Object Access Protocol (SOAP); Web Services Description Language (WSDL); and Universal Description, Discovery, and Integration (UDDI). In contrast, Representational State Transfer (REST) is an architectural style for designing networked applications and exposing web services. REST delivers simplicity and true interoperability and is an alternative to complex mechanism such as CORBA, RPC, or SOAP-based web services and allows using simple HTTP to make calls between machines. The course will explain the REST principles and show how to use the Java standards for developing applications using RESTful API. Students will learn the benefits of and the technical architecture for using REST in applications, including how to design, build, and test RESTful services using Java and JAX-RS. This includes the role of key technologies such as HTTP, Extensible Markup Language (XML), and JavaScript Object Notation (JSON). Students also learn how to consume RESTful services in applications, including the role of JavaScript and Ajax, and how the RESTful approach differs from the SOAP-based approach, while comparing and contrasting the two techniques. Finally, the course will review other web services specifications and standards, and it will describe the use of web services to resolve business applications integration issues. WS-I Basic Profile and other guidance documents and recommended practices will be discussed in the context of achieving high levels of web services interoperability.

Prerequisite(s): 605.202 Data Structures; 605.644 XML Design Paradigms or equivalent XML and Java programming experience; knowledge of the J2EE platform and programming model is recommended.

Instructor(s): Felikson

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(s): 605.202 Data Structures; 605.784 Enterprise Computing with Java, 605.707 Software Patterns, or equivalent experience is recommended.

Instructor(s): Piri

605.787 Front End Web App Development

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., jQuery), server-side tools (e.g., JSON-RPC), and hybrid tools (e.g., the Google Web Toolkit) to simplify the development process. As we delve into several popular client and server-side libraries, we will be examining and paying attention to issues of usability, efficiency, security, and portability.

Prerequisite(s): 605.202 Data Structures; 605.682 Web Application Development with Java or equivalent servlet and JSP experience.

Instructor(s): Chaikin, Shyamsunder

605.788 Big Data Processing Using Hadoop

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

Prerequisite(s): 605.202 Data Structures; 605.681 Principles of Enterprise Web Development or equivalent Java experience.

Course Note(s): This course may be counted toward a three-course track in Data Science and Cloud Computing.

Instructor(s): Pascale, Shyamsunder, Wilson

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.

Prerequisite(s): Seven computer science graduate courses including the foundation courses, three track-focused courses, and two courses numbered 605.7xx, or admission to the post-master's certificate. Students must also have permission of a faculty mentor, the student's academic advisor, and the program chair.

605.802 Independent Study in Computer Science II
Students wishing to take a second independent study in computer science should sign up for this course.

Prerequisite(s): 605.801 Independent Study in Computer Science I and permission of a faculty mentor, the student's academic advisor, and the program chair.

Course Note(s): A student may not receive credit for both 605.759 Independent Project in Bioinformatics and 605.802.

APPLIED PHYSICS

615.611 Classical Physics
This course provides the graduate student in Applied Physics with a review of the basic core topics in classical physics, presented at an entry graduate level. The basic subfields covered are *classical mechanics* (including fluids and acoustics), *thermal* (and statistical) physics, *electromagnetism* (including plasmas and relativity), and *optics*. The four major core topics (in italics) are treated in roughly equal depth. For each topic covered, the fundamental physical laws are introduced to establish a rigorous but intuitive understanding of the basic physics, which is reinforced with hands-on demonstrations and relevant homework assignments. A final exam will also cover the core concepts and principles to check the student's understanding of the key concepts presented. In addition, each student will delve into one subtopic of their own choosing, according to their interest and needs, treating it in more depth as an extended homework assignment, which will be submitted in written form and given as a brief oral presentation before the end of the semester. This course will complement the modern physics course as well as the advanced mathematical methods course offered in the Applied Physics program.

Prerequisite(s): An undergraduate degree in physics, engineering, or a related field.

Instructor(s): Boone

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

Prerequisite(s): An undergraduate degree in physics, engineering, or a related field.

Instructor(s): Staff

615.641 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.

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

Instructor(s): Malik

615.642 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.

Prerequisite(s): Knowledge of vector analysis, partial differential equations, Fourier analysis, and intermediate electromagnetics.

Instructor(s): Awadallah

615.644 Fundamentals of Space Systems and Subsystems I
This course is intended for the physicist or engineer interested in the design of space experiments and space systems. This class presents the fundamental technical background, current state of the art, and example applications in the development of space systems. Topics include systems engineering, space environment, astrodynamics, propulsion and launch vehicles, attitude determination and control, and space power systems. This course is team taught by experts in their respective fields.

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

Course Note(s): This course may be taken for 700-level credit with the additional requirement of a research paper. See 615.744 Fundamentals of Space Systems and Subsystems I.
Instructor(s): Pisacane

615.645 Fundamentals of Space Systems and Subsystems II

This course is intended for the physicist or engineer interested in the design of space experiments and space systems. The course presents the technical background, current state of the art, and example applications in the development of space systems. Topics include spacecraft thermal control, spacecraft configuration and structural design, space communications, risk analysis, command and telemetry systems, spacecraft computer systems, systems integration and test, and space mission operations. This course is team taught by experts in their respective fields.
Prerequisite(s): An undergraduate degree in physics or engineering or the equivalent. Although preferable, it is not necessary to have taken 615.644 Fundamentals of Space Systems and Subsystems I or 615.744 Fundamentals of Space Systems and Subsystems I.
Course Note(s): It is not necessary to have previously taken 615.644 Fundamentals of Space Systems and Subsystems I or 615.744 Fundamentals of Space Systems and Subsystems I. This course may be taken for 700-level credit with the additional requirement of a research paper. See 615.745 Fundamentals of Space Systems and Subsystems II.
Instructor(s): Pisacane

615.646 Physics of Magnetism

This is an introductory course on the magnetic properties of materials and magnetic systems. The emphasis of the course is a mastery of the physics of magnetism along with detailed examples and applications. A basic review of magnetic fields and various classical applications is given. Topics include the physics of paramagnetism, diamagnetism, and ferromagnetism. The magnetism of metals is presented along with discussion of Landau levels and the quantum Hall effect. Various applications are presented in detail, including: magnetic resonance, spectroscopic techniques, magnetoresistance, and spintronics.
Prerequisite(s): An undergraduate degree in engineering, physics, or a related technical discipline. Prior knowledge of electromagnetic interactions would be helpful but is not required.
Instructor(s): Kundu

615.647 Fundamentals of Sensors

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

615.648 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(s): An undergraduate degree in engineering, physics, or a related technical discipline.
Instructor(s): Charles

615.651 Statistical Mechanics and Thermodynamics

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

615.653 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(s): Intermediate mechanics and 615.641 Mathematical Methods for Physics and Engineering.

Instructor(s): C. Najmi

615.654 Quantum Mechanics

This course presents the basic concepts and mathematical formalism of quantum mechanics. Topics include the mathematics of quantum mechanics, the harmonic oscillator and operator methods, quantum mechanics in three dimensions and angular momentum, quantum mechanical spin, quantum statistical mechanics, approximation methods, and quantum theory of scattering.

Prerequisite(s): 615.641 Mathematical Methods for Physics and Engineering or the equivalent.

Instructor(s): A. Najmi, C. Najmi

615.662 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.

Prerequisite(s): 615.642 Electromagnetics, or the equivalent, and 615.654 Quantum Mechanics.

Instructor(s): P. Kundu, A. Najmi

615.665 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, wave-like properties of particles, wave mechanics, atomic and nuclear phenomena, elementary particles, statistical physics, solid state, astrophysics, and general relativity.

Prerequisite(s): Undergraduate degree in physics or engineering.

Instructor(s): Hawkins

615.671 Principles of Optics

This course teaches the student the fundamental principles of geometrical optics, radiometry, vision, and imaging and spectroscopic instruments. It begins with a review of basic, Gaussian optics to prepare the student for advanced concepts. From Gaussian optics, the course leads the students through the principles of paraxial ray-trace analysis to develop a detailed understanding of the properties of an optical system. The causes and techniques for the correction of aberrations are studied. The course covers the design principles of optical Instruments, telescopes, microscopes, etc. The techniques of light measurement are covered in sessions on radiometry and photometry.

Prerequisite(s): Undergraduate degree in physics or engineering.

Instructor(s): C. L. Edwards, Ohl

615.680 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(s): An undergraduate degree in engineering, physics, or a related technical discipline.

Instructor(s): Charles

615.681 Polymeric Materials

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

Prerequisite(s): An undergraduate degree in engineering, physics, or a related technical discipline.

Instructor(s): Staff

615.731 Photovoltaic and Solar Thermal Energy Conversion

This is an advanced course in the application of science and technology to the field of solar energy in general and photovoltaic and solar thermal energy systems in particular.

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

Prerequisite(s): An undergraduate degree in engineering, physics, or a related technical discipline.

Instructor(s): Sova

615.744 Fundamentals of Space Systems and Subsystems I

This course is intended for the physicist or engineer interested in the design of space experiments and space systems. This class presents the fundamental technical background, current state of the art, and example applications in the development of space systems. Topics include systems engineering, space environment, astrodynamics, propulsion and launch vehicles, attitude determination and control, and space power systems. This course is team taught by experts in their respective fields and requires a research paper.

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

Course Note(s): This course may be taken for 600-level credit with the additional requirement of a research paper. See 615.644 Fundamentals of Space Systems and Subsystems I.

Instructor(s): Pisacane

615.745 Fundamentals of Space Systems and Subsystems 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

Prerequisite(s): An undergraduate degree in physics or engineering or the equivalent. Although preferable, it is not necessary to have taken 615.644 Fundamentals of Space Systems and Subsystems I or 615.744 Fundamentals of Space Systems and Subsystems I.

Course Note(s): This course is also offered for 600-level credit and does not require completion of a research paper. See 615.645 Fundamentals of Space Systems and Subsystems II.

Instructor(s): Pisacane

615.746 Nanoelectronics: Physics and Devices

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

Prerequisite(s): An undergraduate degree in engineering, physics, or a related technical discipline. Familiarity with semiconductor device physics would be helpful.

Instructor(s): Staff

615.747 Sensors and Sensor Systems

The primary objective of this course is to present recent advances made in the field of sensors. A broad overview includes optical, infrared, hyperspectral, terahertz, biological, magnetic, chemical, acoustic, and radiation 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.

Prerequisite(s): An undergraduate degree in engineering, physics, or a related technical discipline.

Instructor(s): Fitch

615.748 Introduction to Relativity

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

Instructor(s): Kundu, A. 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(s): 615.642 Electromagnetics or the equivalent completed or taken concurrently.

Instructor(s): Boone

615.753 Plasma Physics

This course is an introduction to the physical processes that govern the "fourth state of matter", also known as plasma. Plasma physics is the study of ionized gas, which is the state of the matter for 99.9% of the apparent universe, from astrophysical plasmas, to the solar wind and Earth's radiation belts and ionosphere. Plasma phenomena are also relevant to energy generation by controlled thermonuclear fusion. The challenge of plasma physics comes from the fact that many plasma properties result from the long-range Coulomb interaction, and therefore are collective properties that involve many particles simultaneously. Topics to be covered during class 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(s): 615.642 Electromagnetics or the equivalent.

Instructor(s): Gkioulidou

615.755 Space Physics

This course studies the physics and the history of our utilization of space, the challenges and mitigation of making in situ observations in space. Topics include the history of solar system exploration; the solar cycle; the electrodynamics of the solar upper atmosphere responsible for the solar wind; and the solar wind interaction with unmagnetized and magnetized bodies—how this leads to planetary bow shocks, comets, and magnetospheres and how they are studied. Practical issues include penetrating radiation and its effects on spacecraft and man in space, magnetospheric storm disruptions of ground power distribution and spacecraft charging in the presence and absence of solar illumination with particular reference to applying this knowledge in exploring the outer solar system and beyond.

Prerequisite(s): 615.642 Electromagnetics or the equivalent.

Instructor(s): Rymer

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(s): 615.654 Quantum Mechanics or the equivalent.

Instructor(s): Staff

615.758 Modern Topics in Applied Optics

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

Prerequisite(s): 615.642 Electromagnetics and 615.782 Optics and MATLAB. A knowledge of laser fundamentals would also be helpful.

Instructor(s): Torruellas

615.760 Physics of Semiconductor Devices

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

Prerequisite(s): An undergraduate degree in engineering, physics, or a related technical discipline. Some familiarity with quantum mechanics would be helpful.

Instructor(s): 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.

Prerequisite(s): Mathematics through calculus.

Instructor(s): 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 615.642 to 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.

Prerequisite(s): Knowledge of vector analysis, partial differential equations, Fourier analysis, basic electromagnetics, and a scientific computer language.

Instructor(s): Awadallah

615.765 Chaos and Its Applications

The course will introduce students to the basic concepts of nonlinear physics, dynamical system theory, and chaos. These concepts will be studied by examining the behavior of fundamental model systems that are modeled by ordinary differential equations and, sometimes, discrete maps. Examples will be drawn from physics, chemistry, and engineering. Some mathematical theory is necessary to develop the material. Practice through concrete examples will help to develop the geometric intuition necessary for work on nonlinear systems. Students conduct numerical experiments using provided software, which allows for interactive learning.

Prerequisite(s): Mathematics through ordinary differential equations. Familiarity with MATLAB is helpful. Consult instructor for more information.

Course Note(s): Access to Whiting School computers is provided for those without appropriate personal computers.

Instructor(s): Liakos

615.769 Physics of Remote Sensing

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

Instructor(s): Chapman

615.772 Cosmology

This course begins with a brief review of tensor calculus and principles of the General theory of relativity, the Freidmann equation and the Robertson-Walker metric. Cosmological models including radiation, matter, and the cosmological constant and their properties are discussed. Observational parameters, the role of dark matter, and the cosmic microwave background, and nucleosynthesis in the early universe are studied. The flatness and the horizon problems are introduced and the role of inflation in the early universe is discussed. Finally, we discuss the origins and the role of density fluctuations in formation of large structures leading to the current Cosmological constant Cold Dark Matter model of the universe.

Prerequisite(s): 615.748 Introduction to Relativity.

Instructor(s): A. Najmi

615.775 Physics of Climate

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

Prerequisite(s): Undergraduate degree in physics or engineering or equivalent, with strong background in mathematics through the calculus level.

Instructor(s): Porter, Winstead

615.778 Computer Optical Design

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

Prerequisite(s): 615.671 Principles of Optics.

Instructor(s): Howard

615.780 Optical Detectors and Applications

This course examines the physics of detection of incoherent electromagnetic radiation from the infrared to the soft X-ray regions. Brief descriptions of the fundamental mechanisms of device operation are given. A variety of illumination sources are considered to clarify detection requirements, with emphasis on solar illumination in the visible and blackbody emission in the infrared. Practical devices, elementary detection circuits, and practical operational constraints are described. An introduction to solid-state and semiconductor physics follows and is then applied to the photodiode, and later to CCD and CMOS devices. A description and analysis of the electronics associated with photodiodes and their associated noise is given. Description of scanning formats leads into the description of spatially resolving systems (e.g., staring arrays). Emphasis is placed on Charged-Coupled Device and CMOS detector arrays. This naturally leads into the discussion of more complex IR detectors and Readout Integrated Circuits that are based on the CMOS pixel. In addition, descriptions of non-spatially resolving detectors based on photoemission and photo-excitation are provided, including background physics, noise, and sensitivity. Selection of optimum detectors and integration into complete system designs are discussed. Applications in space-based and terrestrial remote sensing are discussed, from simple radiometry and imaging to spectrometry.

Prerequisite(s): Undergraduate degree in physics or engineering, preferably with studies in elementary circuit theory, solid-state physics, and optics. Students are expected to be proficient using spreadsheets and/or a programming language such as MATLAB or IDL.

Instructor(s): Hawkins, Darlington

615.781 Quantum Information Processing

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

Prerequisite(s): 615.654 Quantum Mechanics; familiarity with MATLAB, Mathematica, Python, or equivalent helpful.

Instructor(s): Clader

615.782 Optics and MATLAB

This course provides hands-on experience with MATLAB by performing weekly computer exercises revolving around optics. Each module explores a new topic in optics, while simultaneously providing experience in MATLAB. The goal is to bridge the gap between theoretical concepts and real-world applications. Topics include an introduction to MATLAB, Fourier theory and E&M propagation, geometrical optics, optical pattern recognition, geometrical optics and ray tracing through simple optical systems, interference and wave optics, holography and computer-generated holography, polarization, speckle phenomenon, and laser theory and related technology. Students are also expected to complete weekly exercises in MATLAB and a semester project that will allow the student to investigate a particular topic of interest not specifically covered in the course.

Course Note(s): No prior experience with MATLAB is required. While a background in optics is helpful, it is not required.

Instructor(s): Torruellas

615.800 Applied Physics Project

This course is an individually tailored, supervised project that offers the student research experience through work on a special problem related to his or her field of interest.

The research problem can be addressed experimentally or analytically, and a written report is produced. It is recommended that all required Applied Physics courses be completed. Open only to candidates in the Master of Science in Applied Physics program.

Prerequisite(s): It is recommended that all required Applied Physics courses be completed. The Applied Physics project proposal form (ep.jhu.edu/student-forms) must be approved prior to registration.

Course Note(s): Open only to candidates in the Master of Science in Applied Physics program.

Instructor(s): Charles

615.802 Directed Studies in Applied Physics

In this course, qualified students are permitted to investigate possible research fields or to pursue problems of interest through reading or non-laboratory study under the direction of faculty members. Open only to candidates in the Master of Science in Applied Physics program.

Prerequisite(s): The directed studies program proposal form (available from the EP website) must be completed and approved prior to registration.

Course Note(s): Open only to candidates in the Master of Science in Applied Physics program.

Instructor(s): Charles

APPLIED AND COMPUTATIONAL MATHEMATICS

625.108 Calculus I

Differential and integral calculus of functions of one independent variable. Topics include the basic analytic geometry of graphs of functions, and their limits, integrals and derivatives, including the Fundamental Theorem of Calculus. Also, some applications of the integral, like arc length and volumes of solids with rotational symmetry, are discussed. Applications to the physical sciences and engineering will be a focus of this course, as this course is designed to meet the needs of students in these disciplines.

Course Note(s): Not for graduate credit.

Instructor(s): Cutrone

625.109 Calculus II

Differential and integral calculus. Includes analytic geometry, functions, limits, integrals and derivatives, polar coordinates, parametric equations, Taylor's theorem and applications, infinite sequences and series. Some applications to the physical sciences and engineering will be discussed, and the course is designed to meet the needs of students in these disciplines.

Prerequisite(s): 625.108 Calculus I

Course Note(s): Not for graduate credit.

Instructor(s): Cutrone

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(s): Two semesters of calculus.

Course Note(s): Not for graduate credit.

Instructor(s): Davis

625.250 Multivariable and Complex Analysis VL

This course covers fundamental mathematical tools useful in all areas of applied mathematics, including statistics, data science, and differential equations. The course covers basic principles in linear algebra, multivariate calculus, and complex analysis. Within linear algebra, topics include matrices, systems of linear equations, determinants, matrix inverse, and eigenvalues/eigenvectors. Relative to multivariate calculus, the topics include vector differential calculus (gradient, divergence, curl) and vector integral calculus (line and double integrals, surface integrals, Green's theorem, triple integrals, divergence theorem and Stokes' theorem). For complex analysis, the course covers complex numbers and functions, conformal maps, complex integration, power series and Laurent series, and, time permitting, the residue integration method.

Prerequisite(s): Differential and integral calculus.

Course Note(s): Not for graduate credit.

Instructor(s): A. Johnson

625.251 Introduction to Ordinary and Partial Differential Equations

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(s): Differential and integral calculus. Students with no experience in linear algebra may find it helpful to take 625.250 Multivariable and Complex Analysis first.

Course Note(s): Not for graduate credit.

Instructor(s): A. Johnson

625.260 Introduction to Signals and Systems

Linear systems that produce output signals of some type are ubiquitous in many areas of science and engineering. This course will consider such systems, with an emphasis on fundamental concepts as well as the ability to perform calculations for applications in areas such as image analysis, signal processing, computer-aided systems, and feedback control. In particular, the course will approach the topic from the perspectives of both mathematical principles and computational learning. The course will also include examples that span different real-world applications in broad areas such as engineering and medicine. The course is designed primarily for students who do not have a bachelor's degree in electrical engineering or a great deal of prior mathematical coursework. The course will be of value to those with general interests in linear systems analysis, control systems, and/or signal processing. Topics include signal representations, linearity, time-variance, convolution, and Fourier series and transforms. Coverage includes both continuous and discrete-time systems.

Prerequisite(s): Differential and integral calculus.

Course Note(s): Not for graduate credit.

Instructor(s): Woolf

625.601 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(s): Multivariate calculus.

Instructor(s): Hill

625.602 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.

Prerequisite(s): Multivariate calculus and linear algebra.

Instructor(s): Stern

625.603 Statistical Methods and Data Analysis VL

This course introduces statistical methods that are widely used in modern applications. A balance is struck between the presentation of the mathematical foundations of concepts in probability and statistics and their appropriate use in a variety of practical contexts. Foundational topics of probability, such as probability rules, related inequalities, random variables, probability distributions, moments, and jointly distributed random variables, are followed by foundations of statistical inference, including estimation approaches and properties, hypothesis testing, and model building. Data analysis ranging from descriptive statistics to the implementation of common procedures for estimation, hypothesis testing, and model building is the focus after the foundational methodology has been covered. Software, for example R-Studio, will be leveraged to illustrate concepts through simulation and to serve as a platform for data analysis.

Prerequisite(s): Multivariate calculus.

Instructor(s): Bodt, Ermolaeva, Hu, Sadiq, Savkli, Wang

625.604 Ordinary Differential Equations

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

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

Instructor(s): Schug

625.609 Matrix Theory

This course focuses on the fundamental theoretical properties of matrices. Topics will include a rigorous treatment of 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. Essential proof writing techniques and logic will be reviewed and then used throughout the course in exams and written assignments. MATLAB software will be used in some class exercises and homework.

Prerequisite(s): Multivariate calculus

Instructor(s): Devinney, Kuttler, Wall, Woolf

625.611 Computational Methods

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

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

Instructor(s): Sorokina

625.615 Introduction to Optimization

This course introduces applications and algorithms for linear, network, integer, and nonlinear optimization. Topics include the primal and dual simplex methods, network flow algorithms, branch and bound, interior point methods, Newton and quasi-Newton methods, and heuristic methods. Students will gain experience in formulating models and implementing algorithms using MATLAB. No previous experience with the software is required.

Prerequisite(s): Multivariate calculus, linear algebra. Comfort with reading and writing mathematical proofs would be helpful but is not required.

Course Note(s): Due to overlap in much of the subject matter in 625.615 and 625.616, a student may not receive credit towards the MS or post-master's certificate for both 625.615 and 625.616.

Instructor(s): Castello, Ermolaeva, Hill

625.616 Optimization in Finance

Optimization models play an increasingly important role in financial decisions. This course introduces the student to financial optimization models and methods. We will specifically discuss linear, integer, quadratic, and general nonlinear programming. If time permits, we will also cover dynamic and stochastic programming. The main theoretical features of these optimization methods will be studied as well as a variety of algorithms used in practice.

Prerequisite(s): Multivariate calculus and linear algebra.

Course Note(s): Due to overlap in much of the subject matter in 625.615 and 625.616, a student may not receive credit towards the MS or post-master's certificate for both 625.615 and 625.616.

Instructor(s): Castello

625.617 Introduction to Enumerative Combinatorics

The most basic question in mathematics is How many? Counting problems arise in diverse areas including discrete probability and the analysis of the run time of algorithms. In this course we present methods for answering enumeration questions exactly and approximately. Topics include fundamental counting problems (lists, sets, partitions, and so forth), combinatorial proof, inclusion-exclusion, ordinary and exponential generating functions, group-theory methods, and asymptotics. Examples are drawn from areas such as graph theory and block designs. After completing this course students will be practiced in applying the fundamental functions (such as factorial, binomial coefficients, Stirling numbers) and techniques for solving a wide variety of exact enumeration problems as well as notation and methods for approximate counting (asymptotic equality, big-oh and little-oh notation, etc.).

Prerequisite(s): Linear algebra

Course Note(s): This course is the same as 605.623 Introduction to Enumerative Combinatorics.

Instructor(s): Scheinerman

625.620 Mathematical Methods for Signal Processing

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

Prerequisite(s): Mathematics through multivariate calculus, matrix theory, or linear algebra, and introductory probability theory and/or statistics. Students are encouraged to refer any questions to the instructor.

Instructor(s): Woolf

625.623 Introduction to Operations Research: Probabilistic Models

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

Prerequisite(s): Multivariate calculus and a course in probability and statistics (such as 625.603 Statistical Methods and Data Analysis).

Instructor(s): Akinpelu

625.633 Monte Carlo Methods

This course is an introduction to fundamental tools in designing, conducting, and interpreting Monte Carlo simulations. Emphasis is on generic principles that are widely applicable in simulation, as opposed to detailed discussion of specific applications and/or software packages. At the completion of this course, it is expected that students will have the insight and understanding to critically evaluate or use many state-of-the-art methods in simulation. Topics covered include random number generation, simulation of Brownian motion and stochastic differential equations, output analysis for Monte Carlo simulations, variance reduction, Markov chain Monte Carlo, simulation-based estimation for dynamical (state-space) models, and, time permitting, sensitivity analysis and simulation-based optimization.

Prerequisite(s): Linear algebra and a graduate-level statistics course such as 625.603 Statistical Methods and Data Analysis.

Course Note(s): This course serves as a complement to the 700-level course 625.744 Modeling, Simulation, and Monte Carlo. 625.633 Monte Carlo Methods and 625.744 emphasize different topics, and 625.744 is taught at a slightly more advanced level. 625.633 includes topics not covered in 625.744 such as simulation of Brownian motion and stochastic differential equations, general output analysis for Monte Carlo simulations, and general variance reduction. 625.744 includes greater emphasis on generic modeling issues (bias-variance tradeoff, etc.), simulation-based optimization of real-world processes, and optimal input selection.

Instructor(s): Botts

625.636 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.

Prerequisite(s): Familiarity with linear algebra and basic counting methods such as binomial coefficients is assumed. Comfort with reading and writing mathematical proofs is required.

Instructor(s): DeVinney

625.638 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.

Prerequisite(s): Multivariate calculus and linear algebra.

Course Note(s): This course is the same as 605.647 Neural Networks.

Instructor(s): Fleischer

625.641 Mathematics of Finance: Investment Science

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.

Prerequisite(s): Multivariate calculus and an introductory course in probability and statistics (such as 625.603 Statistical Methods and Data Analysis). Some familiarity with optimization is desirable but not necessary.

Instructor(s): Pemy

625.642 Mathematics of Risk, Options, and Financial Derivatives

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

Prerequisite(s): Multivariate calculus, linear algebra and matrix theory (e.g., 625.609 Matrix Theory), and a graduate-level course in probability and statistics (such as 625.603 Statistical Methods and Data Analysis).

Course Note(s): This class is distinguished from 625.641 Mathematics of Finance: Investment Science (formerly 625.439) and 625.714 Introductory Stochastic Differential Equations with Applications, as follows: 625.641 Mathematics of Finance: Investment Science gives a broader and more general treatment of financial mathematics, and 625.714 Introductory Stochastic Differential Equations with Applications provides a deeper (more advanced) mathematical understanding of stochastic differential equations, with applications in both finance and non-finance areas. None of the classes 625.641 Mathematics of Finance: Investment Science, 625.642 Mathematics of Risk, Options, and Financial Derivatives, and 625.714 Introductory Stochastic Differential Equations with Applications is a prerequisite or co-requisite for the other classes; the classes are intended to be complementary. Feel free to contact the instructor(s) should you have any questions about these courses.

Instructor(s): Pemy

625.661 Statistical Models and Regression

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

Prerequisite(s): One semester of statistics (such as 625.603 Statistical Methods and Data Analysis), multivariate calculus, and linear algebra.

Instructor(s): Aminzadeh, Hung, Rooker

625.662 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).

Prerequisite(s): Multivariate calculus, linear algebra, and one semester of graduate probability and statistics (e.g., 625.603 Statistical Methods and Data Analysis). Some computer-based homework assignments will be given.

Instructor(s): Bodt

625.663 Multivariate Statistics and Stochastic Analysis

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

Prerequisite(s): Linear algebra, multivariate calculus, and one semester of graduate probability and statistics (e.g., 625.603 Statistical Methods and Data Analysis).

Instructor(s): Hung

625.664 Computational Statistics

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

Prerequisite(s): Multivariate calculus, familiarity with basic matrix algebra, graduate course in probability and statistics (such as 625.603 Statistical Methods and Data Analysis).

Instructor(s): Nickel

625.665 Bayesian Statistics VL

In Bayesian statistics, inference about a population parameter or hypothesis is achieved by merging prior knowledge, represented as a prior probability distribution, with data. This prior distribution and data are merged mathematically using Bayes' rule to produce a posterior distribution, and this course focuses on the ways in which the posterior distribution is used in practice and on the details of how the calculation of the posterior is done. In this course, we discuss specific types of prior and posterior distributions, prior/posterior conjugate pairs, decision theory, Bayesian prediction, Bayesian parameter estimation and estimation uncertainty, and Monte Carlo methods commonly used in Bayesian statistical inference. Students will apply Bayesian methods to analyze and interpret several real-world data sets and will investigate some of the theoretical issues underlying Bayesian statistical analysis. R is the software that will be used to illustrate the concepts discussed in class.

Prerequisite(s): Multivariate calculus, familiarity with basic matrix algebra, and a graduate course in probability and statistics (such as 625.603 Statistical Methods and Data Analysis).

Course Note(s): Prior experience with R is not required; students not familiar with R will be directed to an online tutorial.

Instructor(s): Botts

625.680 Cryptography

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

Prerequisite(s): Linear algebra and an introductory course in probability and statistics such as 625.603 Statistical Methods and Data Analysis.

Instructor(s): Nickel

625.685 Number Theory

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

Prerequisite(s): Multivariate calculus and linear algebra.

Instructor(s): Stern

625.687 Applied Topology

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

Prerequisite(s): Multivariate calculus, linear algebra and matrix theory (e.g., 625.609 Matrix Theory), and an undergraduate-level course in probability and statistics.

Course Note(s): This course is the same as 605.628 Applied Topology.

Instructor(s): Boswell, Sorokina

625.690 Computational Complexity and Approximation

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

Prerequisite(s): Introductory probability theory and/or statistics (such as 625.603 Statistical Methods and Data Analysis) and undergraduate-level exposure to algorithms and matrix algebra. Some familiarity with optimization and computing architectures is desirable but not necessary.

Instructor(s): Davis

625.692 Probabilistic Graphical Models

This course introduces the fundamentals behind the mathematical and logical framework of graphical models. These models are used in many areas of machine learning and arise in numerous challenging and intriguing problems in data analysis, mathematics, and computer science. For example, the "big data" world frequently uses graphical models to solve problems. While the framework introduced in this course will be largely mathematical, we will also present algorithms and connections to problem domains. The course will begin with the fundamentals of probability theory and will then move into Bayesian networks, undirected graphical models, template-based models, and Gaussian networks. The nature of inference and learning on the graphical structures will be covered, with explorations of complexity, conditioning, clique trees, and optimization. The course will use weekly problem sets and a term project to encourage mastery of the fundamentals of this emerging area.

Prerequisite(s): Graduate course in probability and statistics (such as 625.603 Statistical Methods and Data Analysis).

Course Note(s): This course is the same as 605.625 Probabilistic Graphical Models.

Instructor(s): Woolf

625.695 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.

Prerequisite(s): Graduate course in probability and statistics (such as 625.603 Statistical Methods and Data Analysis) and familiarity with matrix theory and linear algebra.

Course Note(s): This course is also offered in the Department of Applied Mathematics and Statistics (Homewood campus) as 553.639.

Instructor(s): Pemy

625.703 Functions of a Complex Variable VL

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(s): Mathematical maturity, as demonstrated by 625.601 Real Analysis, 625.604 Ordinary Differential Equations, or other relevant courses with permission of the instructor.

Instructor(s): Weisman

625.710 Fourier Analysis with Applications to Signal Processing and Differential Equations

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

Prerequisite(s): Familiarity with differential equations, linear algebra, and real analysis.

Instructor(s): Kuttler

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.

Prerequisite(s): Multivariate calculus and a graduate course in probability and statistics, as well as exposure to ordinary differential equations.

Instructor(s): Woolf

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.

Prerequisite(s): 625.604 Ordinary Differential Equations or equivalent graduate-level ODE class and knowledge of eigenvalues and eigenvectors from matrix theory. (Note: The standard undergraduate-level ODE class alone is not sufficient to meet the prerequisites for this class.)

Instructor(s): Stein

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).

Prerequisite(s): 625.604 Ordinary Differential Equations or equivalent graduate-level ordinary differential equations class and knowledge of eigenvalues and eigenvectors from matrix theory. (Note: The standard undergraduate-level ordinary differential equations class alone is not sufficient to meet the prerequisites for this class.) 625.717 Advanced Differential Equations: Partial Differential Equations is not required.

Instructor(s): Stein

625.721 Probability and Stochastic Process I

This rigorous course in probability covers probability space, random variables, functions of random variables, independence and conditional probabilities, moments, joint distributions, multivariate random variables, conditional expectation and variance, distributions with random parameters, posterior distributions, probability generating function, moment generating function, characteristic function, random sum, types of convergence and relation between convergence concepts, law of large numbers and central limit theorem (i.i.d. and non-i.i.d. cases), Borel-Cantelli Lemmas, well-known discrete and continuous distributions, homogeneous Poisson process (HPP), non-homogeneous Poisson process (NHPP), and compound Poisson process. This course is proof oriented. The primary purpose of this course is to lay the foundation for the second course, 625.722 Probability and Stochastic Process II, and other specialized courses in probability. Note that, in contrast to 625.728, this course is largely a non-measure theoretic approach to probability.

Prerequisite(s): Multivariate calculus and 625.603 Statistical Methods and Data Analysis or equivalent

Instructor(s): Akinpelu, Aminzadeh

625.722 Probability and Stochastic Process II

This course is an introduction to theory and applications of stochastic processes. The course starts with a brief review of conditional probability, conditional expectation, conditional variance, central limit theorems, and Poisson Process. The topics covered include Gaussian random vectors and processes, renewal processes, renewal reward process, discrete-time Markov chains, classification of states, birth-death process, reversible Markov chains, branching process, continuous-time Markov chains, limiting probabilities, Kolmogorov differential equations, approximation methods for transition probabilities, random walks, and martingales. This course is proof oriented.

Prerequisite(s): Differential equations and 625.721 Probability and Stochastic Process I or equivalent.

Instructor(s): Akinpelu

625.725 Theory of Statistics I

This course covers mathematical statistics and probability. Topics covered include basic set theory & probability theory utilizing proofs, transformation methods to find distribution of a function of a random variable, expected values, moment generating functions, well-known discrete and continuous distributions, exponential and location-scale family distributions, multivariate distributions, order statistics, hierarchical and mixture models, types of convergence, Delta methods, the central limit theorem, and direct and indirect methods of random sample generation. This course is a rigorous treatment of statistics that lays the foundation for 625.726 and other advanced courses in statistics.

Prerequisite(s): Multivariate calculus and 625.603 Statistical Methods and Data Analysis or equivalent.

Instructor(s): Aminzadeh

625.726 Theory of Statistics II

This course is a continuation of 625.725. Topics covered include principles of data reduction: minimal sufficient, ancillary, and complete statistics, estimation methods: method of moments, maximum likelihood, and Bayesian estimation, Cramer-Rao inequality, uniformly minimum variance unbiased estimators, the Neyman-Pearson lemma, the likelihood ratio test, goodness-of-fit tests, methods of finding confidence intervals: inverting a test statistic, pivotal quantities, pivoting CDF, and Bayesian intervals, asymptotic evaluation of point estimators, asymptotic efficiency of MLE, asymptotic hypothesis testing, and asymptotic confidence intervals including large sample intervals based on MLE. This course is proof oriented.

Prerequisite(s): 625.725 Theory of Statistics I or equivalent.

Instructor(s): Aminzadeh

625.728 Theory of Probability

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

Prerequisite(s): 625.601 Real Analysis and 625.603 Statistical Methods and Data Analysis.

Instructor(s): Hill

625.734 Queuing Theory with Applications to Computer Science

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

Prerequisite(s): Multivariate calculus and a graduate course in probability and statistics such as 625.603 Statistical Methods and Data Analysis.

Course Note(s): This course is the same as 605.725 Queuing Theory with Applications to Computer Science.

Instructor(s): Nickel

625.740 Data Mining

The field of data science is emerging to make sense of the growing availability and exponential increase in size of typical data sets. Central to this unfolding field is the area of data mining, an interdisciplinary subject incorporating elements of statistics, machine learning, artificial intelligence, and data processing. In this course, we will explore methods for preprocessing, visualizing, and making sense of data, focusing not only on the methods but also on the mathematical foundations of many of the algorithms of statistics and machine learning. We will learn about approaches to classification, including traditional methods such as Bayes Decision Theory and more modern approaches such as Support Vector Machines and unsupervised learning techniques that encompass clustering algorithms applicable when labels of the training data are not provided or are unknown. We will introduce and use open-source statistics and data-mining software such as R and Weka. Students will have an opportunity to see how data-mining algorithms work together by reviewing case studies and exploring a topic of choice in more detail by completing a project over the course of the semester.

Prerequisite(s): Multivariate calculus, linear algebra, and matrix theory (e.g., 625.609 Matrix Theory), and a course in probability and statistics (such as 625.603 Statistical Methods and Data Analysis). This course will also assume familiarity with multiple linear regression and basic ability to program.

Instructor(s): Weisman

625.741 Game Theory

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

Prerequisite(s): Multivariate calculus, linear algebra and matrix theory (e.g., 625.609 Matrix Theory), and a course in probability and statistics (such as 625.603 Statistical Methods and Data Analysis).

Course Note(s): This course is the same as 605.726 Game Theory.

Instructor(s): Castello

625.743 Stochastic Optimization and Control

Stochastic optimization plays a large role in modern learning algorithms and 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 in engineering, computer science, machine learning, and elsewhere, which will be briefly discussed throughout the course. Discrete and continuous optimization problems will be considered. Algorithms for global and local optimization problems will be discussed. Methods such as random search, least mean squares (LMS), stochastic approximation, stochastic gradient, simulated annealing, evolutionary computation (including genetic algorithms), and stochastic discrete optimization will be discussed.

Prerequisite(s): Multivariate calculus, linear algebra, and one semester of graduate probability and statistics (e.g., 625.603 Statistical Methods and Data Analysis). Some computer-based homework assignments will be given. It is recommended that this course be taken only in the last half of a student's degree program.

Instructor(s): Spall

625.744 Modeling, Simulation, and Monte Carlo

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

Prerequisite(s): Multivariate calculus, familiarity with basic matrix algebra, graduate course in probability and statistics (such as 625.603 Statistical Methods and Data Analysis). Some computer-based homework assignments will be given. It is recommended that this course be taken only in the last half of a student's degree program.

Instructor(s): Hill

625.800 Independent Study in Applied and Computational Mathematics

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

625.801/802 Applied and Computational Mathematics Master's Research

This course sequence is designed for students in the master's program who wish to work with a faculty advisor to conduct significant, original independent research in the field of applied and computational mathematics (each course is one semester). A sequence may be used to fulfill two courses within the 700-level course requirements for the master's degree; only one sequence may count toward the degree. For sequence 625.801-802, the student will produce a technical paper for submission to a journal or to a conference with accompanied refereed proceedings. The intent of the research is to expand the body of knowledge in the broad area of applied mathematics, with the research leading to professional-quality documentation. Students with a potential interest in pursuing a doctoral degree at JHU, or another university, should consider enrolling in either this sequence or 625.803-804 to gain familiarity with the research process (doctoral intentions are not a requirement for enrollment).

Prerequisite(s): Completion of at least six courses towards the Master of Science, including 625.601 Real Analysis and/or 625.609 Matrix Theory, 625.603 (Statistical Methods and Data Analysis), and at least one of the following three two-semester sequences: 625.717-718 Advanced Differential Equations: Partial Differential Equations and Nonlinear Differential Equations and Dynamical Systems, 625.721-722 Probability and Stochastic Process I and II, or 625.725-726 Theory of Statistics I and II). It is recommended that the sequence represent the final two courses of the degree.

Course Note(s): The student must identify a potential research advisor from the Applied and Computational Mathematics Research Faculty (ep.jhu.edu/files/acm-research-thesis.pdf) to initiate the approval procedure prior to enrollment in the chosen course sequence; enrollment may only occur after approval. A full description of the process and requirements can be found at ep.jhu.edu/files/acm-research-thesis.pdf.

Instructor(s): Member of ACM Research Faculty

625.803/804 Applied and Computational Mathematics Master's Thesis

This course sequence is designed for students in the master's program who wish to work with a faculty advisor to conduct significant, original independent research in the field of applied and computational mathematics (each course is one semester). A sequence may be used to fulfill two courses within the 700-level course requirements for the master's degree; only one sequence may count toward the degree. For sequence 625.803-804, the student is to produce a bound hard-copy thesis for submission to the JHU library and an electronic version of the thesis based on standards posted at guides.library.jhu.edu/etd (the student is also encouraged to write a technical paper for publication based on the thesis). The intent of the research is to expand the body of knowledge in the broad area of applied mathematics, with the research leading to professional-quality documentation. Students with a potential interest in pursuing a doctoral degree at JHU, or another university, should consider enrolling in either this sequence or 625.801-802 to gain familiarity with the research process (doctoral intentions are not a requirement for enrollment).

Prerequisite(s): Completion of at least six courses toward the Master of Science, including 625.601 Real Analysis and/or 625.609 Matrix Theory, 625.603 (Statistical Methods and Data Analysis), and at least one of the following three two-semester sequences: 625.717-718 Advanced Differential Equations: Partial Differential Equations and Nonlinear Differential Equations and Dynamical Systems, 625.721-722 Probability and Stochastic Process I and II, or 625.725-726 Theory of Statistics I and II). It is recommended that the sequence represent the final two courses of the degree.

Course Note(s): The student must identify a potential research advisor from the Applied and Computational Mathematics Research Faculty (ep.jhu.edu/files/acm-research-thesis.pdf) to initiate the approval procedure prior to enrollment in the chosen course sequence; enrollment may only occur after approval. A full description of the process and requirements for 625.803-804 can be found at ep.jhu.edu/files/acm-research-thesis.pdf.

Instructor(s): Member of ACM Research Faculty

625.805/806 Applied and Computational Mathematics Post-Master's Research

This course sequence is designed for students in the post-master's certificate (PMC) program who wish to work with a faculty advisor to conduct significant, original independent research in the field of applied and computational mathematics (each course is one semester). A sequence may be used to fulfill two courses within the course requirements for the PMC; only one sequence may count toward the certificate. For sequence 625.805–806, the student is to produce a technical paper for submission to a journal or to a conference with accompanied refereed proceedings. The intent of the research is to expand the body of knowledge in the broad area of applied mathematics, with the research leading to professional-quality documentation. Students with a potential interest in pursuing a doctoral degree at JHU, or another university, should consider enrolling in one of these sequences to gain familiarity with the research process (doctoral intentions are not a requirement for enrollment).

Prerequisite(s): At least three courses (four are recommended) toward the post-master's certificate. It is recommended that the sequence represent the final two courses in the post-master's certificate program.

Course Note(s): The student must identify a potential research advisor from the Applied and Computational Mathematics Research Faculty (ep.jhu.edu/files/acm-research-thesis.pdf) to initiate the approval procedure prior to enrollment in the chosen course sequence; enrollment may only occur after approval. A full description of the process and requirements can be found at ep.jhu.edu/acm-process.

Instructor(s): Member of ACM Research Faculty

625.807/808 Applied and Computational Mathematics Post-Master's Thesis

This course sequences is designed for students in the post-master's certificate (PMC) program who wish to work with a faculty advisor to conduct significant, original independent research in the field of applied and computational mathematics (each course is one semester). A sequence may be used to fulfill two courses within the course requirements for the PMC; only one sequence may count towards the certificate. For sequence 625.807-808, the student is to produce a bound hard-copy thesis for submission to the JHU library and an electronic version of the thesis based on standards posted at guides.library.jhu.edu/etd (the student is also encouraged to write a technical paper for publication based on the thesis). The intent of the research is to expand the body of knowledge in the broad area of applied mathematics, with the research leading to professional-quality documentation. Students with a potential interest in pursuing a doctoral degree at JHU, or another university, should consider enrolling in one of these sequences to gain familiarity with the research process (doctoral intentions are not a requirement for enrollment).

Prerequisite(s): At least three courses (four are recommended) towards the post-master's certificate. It is recommended that the sequence represent the final two courses in the post-master's certificate program.

Course Note(s): The student must identify a potential research advisor from the Applied and Computational Mathematics Research Faculty (ep.jhu.edu/files/acm-research-thesis.pdf) to initiate the approval procedure prior to enrollment in the chosen course sequence; enrollment may only occur after approval. A full description of the process and requirements can be found at ep.jhu.edu/files/acm-research-thesis.pdf.

Instructor(s): Member of ACM Research Faculty

INFORMATION SYSTEMS ENGINEERING

635.601 Foundations of Information Systems Engineering

Creating and operating large-scale information systems requires a holistic approach that manages the blending of software, hardware, networks, and security inherent in modern systems. This course introduces key elements and processes required for designing, analyzing, developing, and integrating complex information systems. The course focuses on the systems engineering approach with specific emphasis on design, development, and deployment. Topics covered include requirements engineering, architecture development, security engineering, cost-benefit analysis, information and networking technologies, and operations.

Course Note(s): The required foundation courses may be taken in any order but must be taken before other courses in the degree.

Instructor(s): Chavis, Valenta

635.611 Principles of Network Engineering

This course provides a technical, introductory overview of networking and telecommunications for the engineering practitioner. Topics include voice, data, and video communication system fundamentals, including signaling, frequency concepts, transmission media, multiplexing, spread spectrum, signal encoding, error control, and basic terminology. The OSI and TCP/IP reference models are examined along with the basic concepts of protocols, service interfaces, encapsulation, and layering. 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 IEEE 802.11 wireless; and WAN system fundamentals, such as circuit-switching, packet-switching, IP routing, cellular, satellite, frame relay, label switching, and Asynchronously Transfer Mode.

Instructor(s): Romano

635.621 Principles of Decision Support Systems

This course focuses on the use and application of information systems to support the decision-making process. Knowledge-based systems, neural networks, expert systems, electronic meeting systems, group systems and web-based systems are discussed as a basis for designing and developing highly effective decision support systems. Data models, interactive processes, knowledge-based approaches and integration with database systems are also described. Theoretical concepts are applied to real-world applications.

Instructor(s): T. Felikson

635.631 Foundations of Data Analytics

This foundation course provides an overview of data analysis process, and introduces students to common techniques for data preprocessing, feature extraction, and the creation of statistical models. In particular, students will develop competence in areas of high importance for data scientists and engineers, such as: exploring the trade-off between bias and variance, selecting and creating features, regularizing models, determining optimal hyperparameters, and evaluating model performance. Multiple datasets and data types (e.g., unstructured text, imagery, and time-varying signals) will be considered with the goal of building student confidence across a spectrum of analysis challenges. Particular topics include linear and non-linear regression, decision trees, various approaches to dimensionality reduction, clustering, topic modeling, Bayesian methods, and neural networks.

Prerequisite(s): Programming experience in Python, introductory linear algebra, and probability theory recommended.

Instructor(s): Gearhart

635.661 Principles of Human-Computer Interaction

Well-designed human-computer interaction (HCI) is critical to the success of computer and information systems. This course focuses on the HCI design process and covers the underlying scientific principles, HCI design methodology, and the user-interface technology used to implement HCI. Topics include human cognition, HCI theories, user observation and task analysis, prototyping and evaluation techniques, user interface modalities and graphical user interface components, and accessibility. Selected additional topics may include HCI in website design, support of collaborative work, human interaction with automation, and ubiquitous computing. Student design projects are an integral part of the course. Reading the current HCI research literature is also required.

Instructor(s): Montemayor

635.671 Data Recovery and Continuing Operations

Data recovery and continuing operations refers to the processes, plans, and technologies required for an enterprise to achieve resiliency given unexpected events that may disrupt IT operations. This course provides an overview of the storage technologies to address backup, disaster recovery, and business continuity. Technologies that address auditing, redundancy, and resiliency in the infrastructure (e.g., networks, power, cooling, etc.) are described. Beyond the technologies, processes and plans for continuing operations are covered, including issues such as business continuity, disaster recovery, and risk management.

Prerequisite(s): 635.621 Principles of Decision Support Systems is recommended and may be taken concurrently.

Instructor(s): R. Cost

635.672 Privacy Engineering

Personal information has become a new class of digital property with immense value in commerce and of intense importance to national security and intelligence. Engineering any information system now requires a professional to protect privacy, preserve the information's functional value, and navigate complex domestic and international legal and engineering rules Students will use new visual modeling and analysis tools for designing and executing privacy solutions in both the commercial and governmental sectors. Students will build a final specification for a privacy solution involving regulated personal information.

Instructor(s): Ritter

635.673 Critical Infrastructure

This course focuses on understanding the history, the vulnerability, and the need to protect our Critical Infrastructure and Key Resources (CIKR). We will start by briefly surveying the policies that define the issues surrounding CIKR and the strategies that have been identified to protect them. Most importantly, we will take a comprehensive approach to evaluating the technical vulnerabilities of the sixteen identified sectors, and we will discuss the tactics that are necessary to mitigate the risks associated with each sector. These vulnerabilities will be discussed from the perspective of technical journals/articles that detail recent and relevant network-level CIKR exploits. We will cover well-known vulnerable systems such the Internet, SCADA, and lesser-known systems such as E911 and industrial robots. Students will be challenged with hacker-type home works inspired by current SANS NewsBites and the instructor's research, and will work on a team-based semester-long project.

Instructor(s): Watkins

635.676 Cybersecurity in Information Systems

This course describes the systems security engineering process, focusing on security during the design and implementation of information systems. Topics include architecture and design principles, risk assessment, resiliency, and security metrics. The course addresses emerging topics in cybersecurity including wireless security, cloud security, cross domains and the government standards and processes for secure information systems; surveys many aspects of cybersecurity and its impact on the enterprise; and lays the groundwork to architect and build a natively more secure system that can withstand hacking attacks and continue to deliver basic functionality to the enterprise. We will address the federal government standards and recommendations as well as industry's best practices. Students will cover the basic concepts of information security and research the latest security incidents including external attacks and internal leaks to assess and analyze the exploited vulnerabilities. By learning from current incidents, students can build systems that adapt quickly to emerging threats and potentially continue to serve the enterprise, even while under attack. Additionally, the course addresses the assessment of emerging technologies to determine the potential threats to the enterprise as well as the usability to secure the enterprise. Finally, we will address the subject of legal and ethical access control and the balance between privacy and security.

Instructor(s): Farroha

635.682 Website Development

This course covers the design and implementation of websites. Various web standards, as developed by the World Wide Web Consortium and by browser manufacturers, are studied. HTML 5 specifications are covered, including topics such as text control, images, hypertext links, forms, tables, iframes, and embedded objects (e.g., video and applets). Cascading style sheets, a web scripting language (such as JavaScript), CGI programming, and their use in Dynamic HTML are also covered. Design and development topics include ease of navigation, download time, maintaining a consistent look and feel across multiple pages, making a website work well across multiple browsers, and web server selection and configuration.

Instructor(s): Wright

635.683 E-Business: Models, Architecture, Technologies, and Infrastructure

This course explores fundamental aspects of the e-Business (electronic business) phenomenon that is currently sweeping through the global economy, as well as design principles and technology used to build computer-based systems in order to support the notion of e-Business. E-Business (electronic business) is an umbrella term, an interdisciplinary topic encompassing both business and technology. This topic addresses a variety of business activities, business processes, and strategic business functions conducted over the Internet in order to service customers, to collaborate with business partners, and to maintain and sustain competitive advantage in the networking economy. The course introduces contemporary management philosophies as they have come to be used for the marketing, selling, and distribution of goods and services through the Internet and other electronic media. The course explores approaches of defining drivers and use cases of conducting electronic business. This course provides an overview of principles and analysis of different models of electronic business. It enables students to design effective e-Business models built on a foundation of business concepts, knowledge of the e-Business environment, and an understanding of the influence of the Internet on business stakeholders, including customers, suppliers, manufacturers, service makers, regulators, managers, and employees. In this course students undertake value analysis and learn to describe value propositions. Business architecture and software infrastructure used to engineer and build e-Business systems will be explained. The modern information technologies associated with the delivery of business capabilities over the Internet will be discussed. The course content will be reinforced by a variety of assignments.

Instructor(s): Chittargi, T. Felikson

635.711 Advanced Topics in Network Engineering

This course is designed to provide an advanced treatment of key topic areas in networking and telecommunications for students who have mastered the basic principles of network engineering. Key operational systems, protocols, and technologies are explored in local, wide, metro-area, storage, and wireless networking. Major topic areas include advanced LAN/WLAN technologies (Power over Ethernet, IEEE 802.1x authentication, VLANs, link aggregation, etc.), Storage Area Network technologies, Virtualized/Cloud networking, Optical Networking, IPv6, Spanning Tree and Dynamic IP routing protocols, "Last-Mile" Networking (DSL, Cable Modems, etc.), Label Switching, Multicasting, and Multicast routing, real-time application support mechanisms, Quality of Service protocols, Advanced Transport Layer topics (Congestion Notification, TCP options, etc.), and Network Security (address translation, VPNs, stateful inspection, etc.). A major component of the course will be a design project on one of the topic areas covered in the class.

Prerequisite(s): 635.611 Principles of Network Engineering or 605.671 Principles of Data Communications Networks or equivalent.

Instructor(s): Romano

635.775 Cyber Operations, Risk, and Compliance

This course provides a solid foundation of potential civil and criminal areas of liability, and certain areas in which compliance and risk management are critical. The overarching theme is detection and reduction of potential legal/cybersecurity risks. We start by exploring the legal and regulatory environment that influences and supports cyber-based activities and programs, focusing on multidisciplinary or integrated views of enterprise risk management. We will address key risk management issues from the legal and cybersecurity aspects and analyze legal/cybersecurity issues in several of the critical infrastructure sectors, such as the financial services, healthcare and public health, and transportation systems sectors. We also review legal and regulatory compliance issues to address cybersecurity risk management for systems development, acquisition, and operation. This includes material impacting the manner in which the cyber community operates, for example, FITARA (Federal Information Technology Acquisition Reform Act) Enhancement Act of 2017. We then review the authoritative guidance provided by the National Institute of Standards and Technology (NIST) Cybersecurity Framework. The Framework is voluntary for the sixteen critical information sectors and mandatory for the federal government, hence the focus on NIST. Risk management threat detection and avoidance is analyzed from an integrated legal/cybersecurity perspective, including system objectives to avert legal liability and minimize enterprise and human loss. Examples address financial services, healthcare and public health, and transportation (mobile devices and autonomous vehicles) systems, and cyber-physical systems (CPS) or Internet of Things (IoT). The overall constitutional and statutory basis within which all cyber law and policy operates is identified and reviewed.

Prerequisite(s): Coursework on or experience with the legal system is recommended.

Course Note(s): We provide a guide to assist students in building on their cybersecurity knowledge base. The guide provides key context for general cybersecurity risk management principles and standards.

Instructor(s): Reynolds

635.776 Building Information Governance

Businesses and government agencies confront increasingly complex rules and standards establishing the requirements for how digital information assets are to be created, stored, maintained, accessed, transmitted, received, and disposed. Information system engineers face enormous compliance risks, functional inefficiencies, and remediation costs if they are unprepared to navigate and master all of the technology, business, and legal rules against which digital information must be governed. All of these variables have become more complex as governments and industry partner more closely in counter-terrorism investigations and defenses. This course enables engineers to explore and understand these rules and to develop better leadership skills across teams engaged in designing and managing complex governance projects. Assignments will expose engineers to, and teach them to navigate, the traps that global, cloud-based services present. Students completing the course will be able to contribute effectively to the cutting-edge, demanding projects ahead—"big data" transactions, real-time reporting to official agencies, electronic discovery, privacy, and compliance. Students will be expected to actively participate in class exercises, complete written assignments, and develop and present a final written governance proposal.

635.792 Management of Innovation VL

A critical issue for entrepreneurs and technical managers is how to translate opportunity into competitive advantage. This course explores the management of innovation, including the technical transition of applied R&D into products, the planning and launching of new products, and product management. Management of discontinuous technologies will be explored. The impact of competition by the introduction of new discontinuous technology will be addressed. Managing engineers through the creative process, as well as innovation and technological evolution, will be covered. The course includes both formal and guest lectures. Case studies will be used as an important learning vehicle.

Instructor(s): Husick

635.795 Information Systems Engineering Capstone Project

This course is designed for students who would like to conduct a major independent project involving a substantial enterprise information system design that builds upon elements of the ISE curriculum. The project includes requirements analysis, IT architecture design, network design, software integration, decision support applications, and deployment planning. Interim deliverables include presentations to the course advisors. Project proposals are required and a mentor will be assigned to the student.

Prerequisite(s): Completion of eight courses in the ISE curriculum, including all ISE foundation courses.

Course Note(s): Students may not receive graduate credit for both 635.795 and 635.802 Independent Study in Information Systems Engineering II.

635.801 Independent Study in Information Systems Engineering I

This course permits graduate students in Information Systems Engineering to work with a faculty mentor to explore a topic in depth or conduct research in selected areas. Requirements for completion include submission of a significant paper.

Prerequisite(s): Seven ISE graduate courses including the foundation courses, three concentration area courses, and two courses numbered 635.7xx; or admission to the Post-Master's Certificate. Students must also have permission of a faculty mentor, the student's academic advisor, and the program chair.

635.802 Independent Study in Information Systems Engineering II

Students wishing to take a second independent study in information systems engineering should sign up for this course.

Prerequisite(s): 635.801 Independent Study in Information Systems Engineering I and permission of a faculty mentor, the student's academic advisor, and the program chair.

Course Note(s): Students may not receive graduate credit for both 635.802 and 635.795 Information Systems Engineering Capstone Project.

SYSTEMS ENGINEERING

645.621 Engineering and Measuring Influence

Systems engineering requires an understanding of how people interact with complex systems. Often times, human interaction makes up a substantial portion of system variance and controlling this variance is critical for system performance. Engineers must design interventions to influence people through all aspects of the system. Emerging technology can be used to understand, measure, and assess the effectiveness of interventions to influence human behavior and performance. This course will introduce students to theories of behavior change and provide hands on experience using technologies to measure human-system interaction and influence. Technologies will include biometric, psycho-physiological, and neuroimaging systems.

Instructor(s): McCulloh, McKneely

645.631 Introduction to Model Based Systems Engineering VL

The Introduction to Model Based Systems Engineering course provides an overview of what Model Based Systems Engineering (MBSE) is and how MBSE techniques can be applied to the Systems Engineering process to manage complexity, reduce risk, and potentially streamline the engineering design and development effort. Students will utilize an industry-leading system modeling tool and develop artifacts applied to real-world case studies that reinforce the MBSE concepts of methodology, language, and tools.

Instructor(s): Wolfrom

645.632 Applied Analytics for Model Based Systems Engineering

This course is a continuation of Introduction to Model Based Systems Engineering (MBSE), and provides in-depth exposure to building and using industry-leading system modeling tools to apply and analyze real-world case studies. This course will focus on the application of Model Based Systems Engineering through the use of a modeling language, a modeling method and a system modeling tool as part of the systems engineering process to support requirements, design, analysis, specification, and verification and validation activities of the system. Concepts that were developed from the previous course are now analyzed to assist the systems engineer to explore the solution space using MBSE.

Prerequisite(s): 645.631 Introduction to Model Based Systems Engineering.

Instructor(s): McGervey, Shuman

645.650 Foundations of Human Systems Engineering

Systems are designed, built, and used by humans. Their purpose is to help people meet their goals and perform their tasks. This course introduces the foundations of HSE from which system requirements and design elements are derived. The objective is to provide students with the knowledge of human capabilities and introduce human systems engineering concepts and design principles. Human capabilities include visual, auditory, and touch senses, motion, cognitive processing, and decision making. Human systems engineering concepts and design principles include human factors engineering; training; maintenance; environmental, safety, and health; survivability; habitability; manpower; and personnel.

Prerequisite(s): Admission into the Systems Engineering program.

Instructor(s): Beecher, Cropper, Hatleberg, McKneely

645.651 Integrating Humans and Technology

This class provides a hands-on introduction to human and cognitive systems engineering. Students will learn and apply user-centered research and innovation methods that are used to discover, document and integrate human capabilities, limitations and needs into the systems engineering process, improving the likelihood that the resulting systems are intuitive, efficient, effective and useful. Topics include needs elicitation, workflow analysis, functional allocation, decision making, prototyping, and performance measurement.

Prerequisite(s): 645.662 Introduction to Systems Engineering.

Instructor(s): Goforth, Montemayor

645.662 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 can be brought to bear to address healthcare's challenges and to transform healthcare delivery, as well as the essential role of systems engineering in project management. Topics include defining systems, the system development life cycle, and the systems engineering method. These primary topics are decomposed into requirements analysis, functional design, physical design, design validation, concept development, engineering development, and post development. In addition, the tools and methods at the systems engineer's disposal are also covered. These include risk analysis, configuration management, design trade-offs, modeling and simulation, and interface management, as well as how these subjects are linked to systems program management 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. Students will work as a group to develop the document that serves as a foundation for all systems engineering activity for a specific project, the Systems Engineering Management Plan (SEMP).

Prerequisite(s): Admission into the Systems Engineering program.

Instructor(s): Biemer, Davis, Dever, Devereux, Gianni, Montoya, Olson, Pardoe, Saleh, Sweeney, Syed, Wells

645.667 Management of Systems Projects

The course addresses the management of a technical project from concept to operational use, with emphasis on the functions, roles, and responsibilities of the project manager. From the development of a proposal to the delivery of a product to a customer, the efforts to conceive, plan, budget, schedule, monitor, control/direct, and report the progress of the project are discussed. Throughout the project life cycle, the need for good communications, interface and configuration management, and conflict resolution is emphasized. Students assume the role of project managers who must use management tools such as WBS, EVM, and CPN and who must address typical problems that arise in the conduct of a high-technology systems project.

Prerequisite(s): Admission into the Systems Engineering program.

Instructor(s): Cormier, Hein, Olson, Poston, Saunders, Utara, Young

645.669 Systems Engineering of Deployed Systems

Systems engineering theory typically focuses on the early design and development phases of a system's life cycle, yet over the life of a system, the bulk of engineering effort and the associated costs are not realized until the operations and support (O&S) phase. This course will examine the importance of designing O&S considerations early in a system's life cycle by identifying the appropriate logistic elements and measures, while introducing the necessary analytical processes and tools to support end-to-end life cycle engineering requirements. Manufacturing and production operations will be presented along with the elements that support a system once it is fielded (maintenance planning, reliability prediction, supply support, training, shipping, and system disposal). The course will also explore the requirements and processes associated with major upgrades to deployed systems and the logistics management techniques that must be implemented during initial fielding and deployment. A class project and real-world case studies will underscore the theory and techniques associated with deployed systems engineering.

Prerequisite(s): 645.662 Introduction to Systems Engineering or 645.667 Management of Systems Projects. College-level Statistics (College-level Calculus preferred but not required).

Instructor(s): Mayoral

645.742 Management of Complex Systems

Traditional systems engineering is usually applied to closed, precise, and recursive systems with the assertion that the methodologies used can be scaled up to more elaborate systems of systems. This course addresses the more realistic and emerging field of complex systems, where multiple current development efforts with disparate and nonlinear attributes characterize the system components. Managing complex systems must account for the likelihood of multiple disciplines, differing scales, often unpredictable future states, irreducible uncertainty, and nonlinear behavior. Customers, 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 approaches to managing complex systems and to use adaptive strategies and tools. 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/government systems. Students will be expected to discuss several readings and complete academic papers to explore in depth one or more of the concepts discussed.

Prerequisite(s): 645.769 System Test and Evaluation or advisor and instructor approval.

Course Note(s): Selected as one of the electives in the Master of Science in Engineering or Master of Science program or a required course for the post-master's certificate.

Instructor(s): Crownover

645.753 Enterprise Systems Engineering

Enterprise systems engineering is a multidisciplinary approach combining systems engineering and strategic management to address methods and approaches for aligning system architectures with enterprise business rules and the underlying IT architecture; development and implementation consistent with enterprise strategic objectives; and the total enterprise system and capabilities, with diverse complex subsystems. This course uses the systems engineering life cycle as a framework for linking outcome-based engineering analysis and decision making with enterprise strategic objectives, addressing methods and tools for managing complexity, determining measures of effectiveness, and assessing return on investment from an engineering perspective. The complex nature of enterprises will be discussed, including the multiplicity of technical and business components involved in delivering enterprise capability, as well as methods for modeling and analysis of their interdependence. Business and technical interdependencies among 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.

Prerequisite(s): 645.769 System Test and Evaluation or advisor and instructor approval.

Course Note(s): Selected as one of the electives in the Master of Science in Engineering or Master of Science program or a required course for the post-master's certificate.

Instructor(s): Dahmann, Ziarko

645.754 Social and Organizational Factors in Human Systems Engineering

The objective of this course is to provide students with the knowledge of organizational structure, social interaction, and group behavior needed to reflect the full context of use in the practice of systems engineering. It examines the characteristics of organizations and of social contexts that influence system requirements and design and describes systems engineering processes for discovering, representing, and analyzing such information in practice. It covers the application of these factors throughout the system life cycle. Topics covered include groupware, social networks, organizational change, organizational culture, high reliability organizations, leadership, and engineering ethics.

Prerequisite(s): 645.662 Introduction to Systems Engineering.

Instructor(s): Bos, Gersh

645.755 Methods in Human-System Performance Measurement and Analysis

This course focuses on human-systems performance measurement (HsPM) methods used to determine whether human-system requirements are met and if the system's design provides effective and efficient human-system performance. Students will gain knowledge of HsPM study design protocols, data collection tools and methods, analysis techniques and processes, and procedures required to execute studies with human participants. The course will provide students with an understanding of HsPM in the context of system design; workplace design; environment, safety, and occupational health; training; and maintenance. Students will be exposed to heuristic evaluations; modeling and simulation of human tasking, including tools for measuring physical limitations, cognitive load, and fatigue; and system testing with the human element.

Prerequisite(s): 645.662 Introduction to Systems Engineering.

Instructor(s): Beecher, Whaley

645.756 Metrics, Modeling, and Simulation for Systems Engineering

This course takes an integrated, in-depth view of foundational statistical concepts, modeling, and simulation techniques. Knowledge of typical system-level key performance parameters and their stochastic characterization is critical to the systems engineering process as the basis for decision-making from early system conceptualization through retirement. Relevant probability and statistics concepts are covered in context of SE decision points. Techniques in experimental design, data collection, analysis, and modeling of system metrics as a function of system use and environment are explored as they pertain to characterizing system, subsystem, and component performance. Finally, implementing models in analytic simulations to support requirements, design, upgrade, and replacement/retirement phases of the SE process provides the systems engineer with a solid foundation for making and justifying difficult decisions.

Prerequisite(s): 645.662 Introduction to Systems Engineering, 645.667 Management of Systems Projects, and 645.767 System Conceptual Design.

Instructor(s): West, Youngblood

645.757 Foundations of Modeling and Simulation in Systems Engineering

This course provides an introduction to the field of modeling and simulation (M&S) from the perspective of M&S as an essential tool for systems engineering. The course presents an overview of the M&S discipline, the model/simulation development process, the types of models and simulations used in the various phases of the systems engineering life cycle, and the verification, validation, and accreditation of models and simulation. The strengths and limitations of M&S are explored with respect to the application of M&S use in systems engineering. Examples are given for several types of systems, including both military and civilian systems. Statistical methods used in applying M&S in systems engineering are explained. The Arena process modeling tool is used for some examples, an individual assignment, and a team-based project. Upon completion of the course, the student will be able to explain when M&S will provide meaningful support to a technical program, select the appropriate modeling techniques for a given task, plan the development of a model/simulation and the modeling of its input data, and analyze the results of its execution to support decisions at key milestones of a system's life cycle.

Prerequisite(s): 645.662 Introduction to Systems Engineering.

Instructor(s): Coolahan, Jones

645.758 Advanced Systems Modeling and Simulation

This course is a continuation of 645.757 Foundations of Modeling and Simulation in Systems Engineering and provides in-depth exposure to the field of modeling and simulation (M&S) from the perspective of M&S as an essential tool for systems engineering. Advanced statistical methods are used to conduct requirements-driven simulation analysis and experimentation. The course provides treatment of advanced M&S topics, including verification, validation, and accreditation techniques; methods for simulation interoperability and composability; modeling of the system environment, both natural and man-made; modeling of system costs; and the establishment of collaborative M&S environments. The course also explores continuous and real-time simulation. Students are exposed to the techniques used to form conceptual models of mechanical (both translational and rotational), electrical, fluid, thermal, biological, and hybrid systems. The conceptual models are transformed into mathematical models and implemented in a modern simulation package. State-of-the-art tools are explored, and each student is given the opportunity to conduct a simulation study of a complex system. Each student will present a case study and complete a project. Upon completion of the course, the student will be able to conduct or lead the development of the model of a complex physical system, model the input data, and analyze the results to support decisions at key milestones of a system's life cycle.

Prerequisite(s): 645.757 Foundations of Modeling and Simulation in Systems Engineering.

Instructor(s): Coolahan, Jones

645.761 Systems Architecting

As the systems that systems engineers face become more complex, it is no longer sufficient to use "good engineering practices." The complex systems of today need to be architected before design work can begin. This course examines the principles and art of systems architecting when developing both individual systems and systems that are components of a system or federation of systems. The objective is to provide students with the principles, techniques, and hands-on experience of architecting modern, complex systems. Students will learn the latest architecture development techniques using DoD and commercial architectural frameworks, then extend those frameworks to specific problems involving unique systems development environments. Topics include the management of underlying system and data models and the special architecting requirements of command, control, and communications systems. Special attention will be placed on visualizing architecture artifacts-qualitatively and quantitatively evaluating architectures and the systems model they represent-and utilizing system architectures for investment decisions. Case studies from actual experiences will be presented.

Prerequisite(s): 645.769 System Test and Evaluation or advisor and instructor approval.

Course Note(s): Selected as one of the electives in the MSE or MS program or a required course for the post-master's certificate.

Instructor(s): Ruben, Schneider, Smithson, Topper

645.764 Software Systems Engineering

This course for systems engineers covers software engineering principles, artifacts, and approaches for the development of software systems. Topics include software engineering processes and metrics; real-time, distributed, configurable, and object-oriented software; alignment of software systems with overall system design; software-unique aspects of planning, requirements, architecture analysis, design, implementation, testing, and maintenance; understanding important software engineering constraints (performance, security, networking, etc.); and technology trends in software engineering today. Student teams will conduct case studies for a project.

Prerequisite(s): 645.662 Introduction to Systems Engineering and 645.667 Management of Systems Projects or permission from the student's academic advisor and the course instructor.

Course Note(s): For Technical Management students, as of fall 2017, 595.763 Software Engineering Management is no longer offered and 645.764 Software Systems Engineering is the replacement course. 645.764 will fulfill the Technical Management requirement. Students may not enroll in this course if they have already completed 595.763 Software Engineering Management.

Instructor(s): Saunders, Tamer, Valencia

645.766 Systems Engineering Advanced Technology

This course emphasizes the impact of recent technological advances on new products, processes, and needs, as well as the roles of the technical manager, program manager, and systems engineer in rapidly-evolving technologies. Subject areas and lecture content track current topics of interest, such as trends and developments in hypersonics, communications, computers, anti-tamper technologies, intelligent machines, nanotechnology, and robotics. Advanced technologies in application areas such as transportation, space, manufacturing, and biomedicine are also discussed. Relatively new systems engineering approaches such model-based systems engineering, agile systems engineering, and "DevOps" are included in the syllabus. In addition, a special enrichment topic for this Cohort is a discussion on the ethics of autonomous weapons led by an internationally-known expert on the subject. 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.

Instructor(s): Strawser

645.767 System Conceptual Design

This course addresses in detail the systems engineer's responsibilities and activities during the conceptual phases of a system development program. Systems engineering tools commonly employed at this stage of a program are presented along with selected problems that illustrate both the applicability and limitations of commonly employed tools and procedures. The course steps through conceptual design beginning with analysis of needs and objectives and proceeding to the exploration of alternative concepts and the selection of a concept that best meets goals of performance, timeliness, and affordability. Topics include definition of operational scenarios, functional analysis, risk assessment, system tradeoffs, measures of effectiveness, and requirements formulation. Emphasis is on the application of these systems engineering techniques in a team environment to a class project. Students apply systems engineering methods learned from reading and lectures to the development of a realistic system in an ongoing project in a team format.

Prerequisite(s): 645.764 Software Systems Engineering or permission of the student's advisor and the course instructor.

Instructor(s): Anderson, Flanigan, Ryder, Secen, Schneider, Starr, Topper

645.768 System Design and Integration

This course addresses the systems engineering objectives, responsibilities, and activities during the demonstration and validation and the engineering and manufacturing development phases of a system development program.

Systems engineering procedures and tools employed during these phases are identified and their use illustrated. Topics include the relationship between a system specification and the system design, systems engineering management plans, risk management, system development models, customer integration into the design process, and design disciplines and practices. The course uses a system problem scenario extensively to illustrate systems engineering principles and specific product design issues.

Prerequisite(s): 645.767 System Conceptual Design or permission of the student's advisor and the instructor.

Instructor(s): Biemer, Bierria, Fidler, Harmatuk, Montoya, Olson, Ryder, Saunders, Secen, White

645.769 System Test and Evaluation

This course focuses on the application of systems engineering principles to the test and evaluation of system elements and, ultimately, of the total system. Test requirements, selection of critical test parameters, analysis of test results, and determination of remedial action in the event of discrepancies are all systems engineering functions. Topics include validation and verification, similarities and differences in the nature of hardware and software testing, test tools and test procedures, testing during hardware-software integration, quality assurance test, environmental test, and operational test and evaluation. Student problems include scenario case studies using examples developed in the several previous courses.

Prerequisite(s): 645.768 System Design and Integration or permission of the student's advisor and the instructor.

Instructor(s): Davis, Fidler, Harmatuk, Kim, Kryzstan, O'Connor, Sprigg, Tarchalski, Ziarko

645.771 System of Systems Engineering

This course addresses the special engineering problems associated with conceiving, developing, and operating systems composed of groups of complex systems closely linked to function as integral entities. The course will start with the underlying fundamentals of systems' requirements, design, test and evaluation, and deployment, and how they are altered in the multi-system environment. These topics will then be extended to information flow and system interoperability, 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 systems of systems, including missile defense and combatant vehicle design, as well as selected commercial examples.

Prerequisite(s): 645.769 System Test and Evaluation or advisor and instructor approval.

Course Note(s): Selected as one of the electives in the MSE or MS program or a required course for the post-master's certificate.

Instructor(s): Biemer, Fidler

645.800 Systems Engineering Master's Project

This course provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific practical project that is suggested by the student and is presented in a formal proposal. The product of the system project is a final report; also required are interim reports and an oral presentation to permit review of the project objectives and approach. This is an independent course that has no formal classes; the student is responsible for developing their own project timeline and works to complete it within one semester. A student typically has a mentor who is a member of the systems engineering faculty. The program chair, vice chair, and mentor review proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses.

Prerequisite(s): 645.769 System Test and Evaluation and an approved project concept from their project mentor and project instructor.

Course Note(s): Students who plan to register for this course will need to have a project mentor and a topic for their project and should contact the Systems Engineering Program Office (443-778-6002) four to six weeks prior to the semester start date.

Instructor(s): Flanigan, Utara

645.801 Systems Engineering Master's Thesis

This course is the first of a two-semester requirement designed for students in the Systems Engineering Master's program. Thesis students will conduct independent research in the field of systems engineering, under the guidance of an advisor. The intent of the Master's Thesis 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. In this course, students will gain a foundation in conducting graduate-level, academic research, including an introduction to research paradigms and methodologies, problem/research question formulation, research design, literature search and critique, proposal preparation, data collection and analysis, research ethics, and the canons of research for engineering and science. At the end of this semester, the student will present their research proposal to their thesis committee. Students interested in pursuing a doctoral degree should enroll in the Thesis Option.

Prerequisite(s): Completion of all other courses applicable to the Systems Engineering master's degree.

Course Note(s): Students who plan to register for this course will need to contact the Systems Engineering Program Office (443-778-6002) four to six weeks prior to the semester start date.

Instructor(s): Strawser

645.802 Systems Engineering Master's Thesis

This course is the second of a two-semester requirement designed for students in the systems engineering master's program. Thesis students will conduct independent research in the field of systems engineering, under the guidance of an advisor. The intent of the Master's thesis 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. In this semester, the student will conduct the research outlined in the research proposal developed during 645.801, with guidance and oversight from their thesis advisor. At the end of the semester, the student will deliver their thesis paper acceptable for publishing in a professional peer-reviewed journal and will present a defense of their research to their Thesis Committee. Students interested in pursuing a doctoral degree should enroll in the Thesis Option.

Prerequisite(s): Completion of 645.801 Systems Engineering Master's Thesis, the first semester of this two-semester course.

Instructor(s): Strawser

645.803.804 Post-Master's Systems Engineering Research Project

This course is designed for students in the Systems Engineering Post Master's Advanced Certificate Program, who will work with an advisor to conduct independent research in the field of systems engineering leading to a paper that is publishable in a refereed journal. It is also desirable the paper be presented in a professional meeting. The intent of the research is to advance the body of knowledge and the understanding of systems engineering practices, the improvement of systems engineering practices in industry and in government, the evolution of systems engineering tools and techniques, and the solution of systems development issues in the acquisition of advanced systems.

Prerequisite(s): MSE or MS in Systems Engineering and three of the four required advanced post-master's systems engineering courses.

Course Note(s): Students who plan to register for this course will need to contact the Systems Engineering Program Office (443-778-6002) four to six weeks prior to the semester start date.

HEALTHCARE SYSTEMS ENGINEERING

655.662 Introduction to Healthcare Systems Engineering

This course introduces students to the fundamental principles of healthcare systems engineering and their application to the development of complex systems. It describes how the systems engineering viewpoint differs from that of the healthcare provider, as well as the essential role that systems engineering plays as an integral component of program management. Topics include integrated systems engineering life cycle purpose and constructs, delineation of different complex system types, requirements analysis, concept definition, system synthesis, design trade-offs, 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 healthcare systems engineer must acquire concerning the characteristics of the diverse components that constitute the total system. Special topics such as architectures, interfaces, simulation and models, and test and evaluation are discussed in relation to the healthcare systems engineering viewpoint. Students address typical systems engineering problems that highlight important healthcare issues and methods of technical problem resolution.

Instructor(s): Montoya

655.667 Management of Healthcare 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 healthcare systems project manager. From the development of a proposal to the delivery of a product and/or service to a customer, the efforts to conceive, plan, budget, schedule, monitor, control/direct, and report the progress of the project are discussed. Throughout the project life cycle, the need for good communications, interface and configuration management, and conflict resolution is emphasized. Students assume the role of project managers who must use management tools such as WBS, EVM, and CPN and who must address typical problems that arise in the conduct of a high-technology systems project.

Instructor(s): Dever

655.767 Healthcare System Conceptual Design

This course addresses in detail the healthcare systems engineer's responsibilities and activities during the conceptual phases of a healthcare system development program. Systems engineering tools commonly employed at this stage of a program are presented along with selected problems that illustrate both the applicability and limitations of commonly employed tools and procedures to the solving current healthcare issues. The course steps through conceptual design beginning with analysis of needs and objectives and proceeding to the exploration of 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.

Prerequisite(s): 655.662 Introduction to Healthcare Systems Engineering and 655.667 Management of Healthcare Systems Projects, or permission of the student's faculty advisor and the course instructor.

Instructor(s): Flanigan

655.768 Healthcare System Design and Integration

This course addresses the healthcare systems engineering objectives, responsibilities, and activities during two phases of the system development life cycle: demonstration and validation, and engineering and manufacturing development. Healthcare systems engineering procedures and tools used during these phases are identified and their use illustrated. Topics include the relationship between a system specification and the system design, risk management and patient safety, system design models, healthcare provider and patient integration into the design process, and healthcare design disciplines and practices. The course uses a healthcare system scenario extensively to illustrate systems engineering principles and specific product design issues.

Prerequisite(s): 655.767 Healthcare System Conceptual Design or permission of the student's faculty advisor and the instructor.

Instructor(s): Montoya, Obringer

655.769 Healthcare System Test and Evaluation

This course focuses on the application of systems engineering principles to the test and evaluation of healthcare 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(s): 655.768 Healthcare System Design and Integration or permission of the student's faculty advisor and the instructor.

Instructor(s): Faculty

655.771 Healthcare Systems

This course will cover the fundamental elements of modern healthcare systems, including their structure, processes, and relation to information systems and system interfaces. It also covers the organization, financing, and delivery of healthcare in the United States. It also discusses several potential small and large-scale reforms to the U.S. healthcare system and evaluates their likely effects on healthcare spending, quality of care, and access to care.

Prerequisite(s): 655.767 Healthcare System Conceptual Design or permission of the student's faculty advisor and the instructor.

Instructor(s): Faculty

655.772 Healthcare Networks and Databases

This course covers the various healthcare databases, both internal and external to care centers, and how they are networked together. The course will look at the capabilities and interfaces of current electronic medical records (EMRs) that serve as the starting point for patient care. Data collection and data entry limitations will be discussed in terms of how they can affect patient care.

Prerequisite(s): 655.767 Healthcare System Conceptual Design or permission of the student's faculty advisor and the instructor.

Instructor(s): Faculty

655.773 Designing for Patient Safety

This course will cover the identification, assessment, and mitigation of risk in healthcare systems. Specific topics will allow students to examine the causes of and systematic ways of preventing medication errors, patient handoff process issues, and procedural mistakes.

Prerequisite(s): 655.767 Healthcare System Conceptual Design or permission of the student's faculty advisor and the instructor.

Instructor(s): Faculty

655.800 Healthcare Systems Engineering Capstone Project

This course provides the experience of applying systems engineering principles and skills learned in the formal courses to a specific practical healthcare system project that is suggested by the student and is presented in a formal proposal. The product of the system project is a final report; also required are interim reports and an oral presentation to permit review of the project objectives and approach. A student typically has a mentor who is a member of the Systems Engineering faculty. The program chair and mentor review proposals and reports. The total time required for this course is comparable to the combined class and study time for the formal courses (formerly 645.770). It is self-paced and often takes more than one semester to complete.

Prerequisite(s): 655.769 Healthcare System Test and Evaluation or permission of the program chair.

Instructor(s): Faculty

SPACE SYSTEMS ENGINEERING

675.600 Systems Engineering for Space

This course introduces students to the fundamental principles of systems engineering and their particular application to the development of space systems. It describes how the systems engineering viewpoint differs from that of the engineering specialist, as well as the essential role that systems engineering plays across the mission design life cycle. Topics include requirements analysis, trade studies, concept definition, interface definition, system synthesis, and engineering design. Techniques and analysis methods for making supportable quantitative decisions will also be explored, along with risk assessment and mitigation planning. The importance of thorough systems engineering from the initiation of the project through launch and flight operations will be emphasized. This is intended as the first course in the Space Systems Engineering program curriculum so that the student establishes a firm grasp of the fundamentals of systems engineering as applied to space programs. Examples will be presented from real space missions and programs, with assignments, special topics, and a team project focused on typical space systems engineering problems and applied methods of technical problem resolution.

Prerequisite(s): Admission into the SSE program, or with approval of the instructor.

Instructor(s): Devereux, Pardoe

675.601 Fundamentals of Engineering Space Systems I

The effective development of space systems is predicated on a firm understanding of the foundational technical and systems engineering components necessary to both comprehend the design task and formulate an appropriate solution. For engineers and technical managers seeking to develop this working knowledge and associated skills, this course will provide an overview of the key elements comprising space systems and an analytic methodology for their investigation. With a strong systems engineering context, topics will include fundamentals on astrodynamics, power systems, communications, command and data handling, thermal management, attitude control, mechanical configuration, and structures, as well as techniques and analysis methods for remote sensing applications. In addition, a number of supplemental topics will be included to provide further breadth and exposure. This is the first course of a two-semester sequence that features a combination of instruction from practitioner subject matter experts, and a team design project.

Prerequisite(s): Completion of 675.600 Systems Engineering for Space, or with approval of the instructor.

Instructor(s): Bauer, Rogers

675.602 Fundamentals of Engineering Space Systems II

This course will build on the foundational elements introduced in 675.601 Fundamentals of Engineering Space Systems I, expanding on the breadth and depth of prior subject matter treatment, as well as their integrated application. Classes will again feature a combination of instruction from subject matter experts and a team design project.

Prerequisite(s): Completion of 675.600 Systems Engineering for Space and 675.601 Fundamentals of Engineering Space Systems I, or with approval of the instructor.

Instructor(s): Bauer, Rogers

675.640 Satellite Communications Systems

This course presents the fundamentals of satellite communications link design and an in-depth treatment of practical considerations. Existing commercial, civil, and military systems are described and analyzed, including direct broadcast satellites, high throughput 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. The impact of new technology on future systems in this dynamic field is discussed.

Prerequisite(s): 525.616 Communication Systems Engineering or equivalent, or with approval of the instructor.

Course Note(s): This course is cross-listed with 525.640 Satellite Communications Systems.

Instructor(s): DeBoy

675.650 Mathematics for Space Systems

This course is designed to teach Mathematical Methods commonly employed for engineering Space Systems. The course will provide a solid technical foundation in mathematics so the students can apply this knowledge to this broad field. Topics will include select, applicable methods from vector calculus, linear algebra, differential equations, transform methods, complex variables, probability, statistics, and optimization. Various applications to real problems related to space systems and technical sub-disciplines will be used during the semester. No prior knowledge of advanced mathematics is assumed and important theorems and results from pure and applied mathematics are taught as needed during the course. Examples and relevant applications will be utilized throughout the course to further clarify the mathematical theory.

Prerequisite(s): The course requires prior knowledge of college calculus and algebra, or approval of the instructor.

Instructor(s): Malik

675.691 Electro-Optical Space Systems

The goal of this course is to engage the student with multiple design studies of subsystems of space-based electro-optic systems. The technical and scientific elements necessary to be successful with these studies will be presented during the lectures. The concepts and technologies behind elements such as photon detectors, imaging elements over many spectral bands, optical elements and systems typically used in space sensors, and active optical sources will be described. These concepts and technologies will be the fundamental elements used to describe the various sensor types and modalities used in space electro-optical systems.

Prerequisite(s): An undergraduate or graduate degree in a quantitative discipline (e.g., engineering, computer science, mathematics, physics, or equivalent), or with approval of the instructor.

Instructor(s): Young

675.701 Applications of Space Systems Engineering

The ability to effectively apply knowledge and skills to new problems and situations is critical in the development of space systems. Building upon the foundational systems engineering and technical skills developed through prior coursework, this course will introduce further topics related to areas of active exploration and investigation, as well as practical details pertaining to mission formulation and assessment. Classes will be structured to include both information exchange led by subject matter experts from across the community and active group discourse. In addition, a number of topical case studies will be worked by students in both individual and group formats. Students will be asked to explore, in depth, various advanced areas of space systems engineering challenges and share information with each other in online discussions.

Prerequisite(s): Completion of 675.600 Systems Engineering for Space, 675.601 Fundamentals of Engineering Space Systems I, and 675.602 Fundamentals of Engineering Space Systems II, or with approval of the instructor.

Instructor(s): Binning, Seifert

675.710 Small Satellite Development and Experimentation

The capstone course in the Space Systems Engineering Program will introduce practical methods and tools used for evaluating the design and implementation of space systems—with a particular focus on small satellites and CubeSats. This will be principally achieved through a significant experimentation laboratory component intended to reinforce analytical experience with empirical exposure and insight. The laboratory will build on prior foundational understanding of spacecraft subsystem design and performance, through a structured series of experiments and investigations to be conducted in small student teams. It will utilize tabletop satellite simulator kits that are especially designed for hands-on educational purposes, while drawing heavily on the analysis methods and tools developed in the Fundamentals of Engineering Space Systems I/II sequence. All work is aimed at preparing for and executing a single long-residency-weekend exercise, nominally held the 10th week of the semester at the Johns Hopkins University Applied Physics Laboratory. In lieu of meeting during normal class time during the 10th week, the lab will meet the Friday, Saturday, and Sunday immediately following the normal class date. The lab component will have a mandatory set of core hours during a time period running from Friday at 5 p.m. through Sunday at 12 p.m.; students are responsible for their own travel and accommodations, as required. An optional tour of APL space facilities is planned for 4 p.m. on Friday. There will be no further classes following the residency weekend, with only final laboratory deliverables due per provided instructions.

Prerequisite(s): Completion of 675.600 Systems Engineering for Space, 675.601 Fundamentals of Engineering Space Systems I, and 675.602 Fundamentals of Engineering Space Systems II, or with approval of the instructor.

Instructor(s): Knuth, Ostdiek

675.711 Ground System Engineering and Mission Operations

This course will focus on the critical functions performed by ground systems and mission operations throughout the space systems life-cycle and their integrated application. Course topics will include planning and sequencing, uplink and control, testing, real-time operations, communications, data management, data analysis, and assessment. Students will learn about end-to-end best practices that pertain to most missions and how ground systems and mission operations concepts are tailored across a diversity of missions. Examples will be presented from real space missions and programs, with assignments, special topics, and a team project focused on typical ground system engineering problems, mission operations challenges, and applied methods of technical problem resolution.

Prerequisite(s): Completion of 675.600 Systems Engineering for Space and 675.601 Fundamentals of Engineering Space Systems I, or with approval of the instructor.

Instructor(s): Berardino, Sepan

675.751 Space Weather and Space Systems

This course will explore the space environment in the context of its impact on space system operations. Topics include the impacts of ionospheric variability on HF propagation, satellite communications, and GPS; impacts of energetic charged particles on spacecraft; impacts of auroral precipitation on radar and communication systems; and impacts of varying geomagnetic activity on power grids and space situational awareness. Lectures and homework assignments will prepare engineers to quantify and mitigate space weather impacts, and a final project will consist of a detailed analysis on a system of interest to the student.

Prerequisite(s): An undergraduate or graduate degree in a quantitative discipline (e.g., engineering, computer science, mathematics, physics, or equivalent), or with approval of the instructor.

Instructor(s): J. Comberiate

675.752 Attitude Determination and Control of Space Systems VL

The Attitude Determination and Control Subsystem, or ADCS, is intimately connected with all the other spacecraft subsystems, and will be studied in the context of the systems engineering of the whole spacecraft and its mission. Students will examine the requirements imposed on the ADCS, and will explore how to meet those requirements. To this end, it starts with a student's understanding of rigid-body dynamics as it relates to spacecraft dynamics and will introduce common and classical approaches to problems encountered in the design of this critical spacecraft subsystem. The course will also include a team design project involving an ADCS for a small spacecraft.

Prerequisite(s): Completion of 675.600 Systems Engineering for Space and 675.601 Fundamentals of Engineering Space Systems I, or with approval of the instructor.

Instructor(s): Shankar

675.754 Flight Software for Space Systems

This survey course reviews the architectures, designs, and implementations of spacecraft flight software systems. The course provides an overview of typical command and data handling software functions and the open-source tools, frameworks, and applications that can implement them. A semester-long programming assignment is provided to build a working flight software system. Special topics include application to resource-constrained Internet-of-Things (IoT) devices, spacecraft security, and space-based networking. Flight software encompasses the complete set of computer instructions running on every processor on a spacecraft.

Prerequisite(s): Completion of 675.600 Systems Engineering for Space and 675.601 Fundamentals of Engineering Space Systems I, experience programming in C, or with approval of the instructor.

Instructor(s): Birrane

675.756 Antenna Design for Space Systems VL

This course presents an engineering approach to the design of antennas for space systems. Students will examine antennas for both large and small space based platforms in earth orbit and beyond. Antenna design is presented in the context of the space environment with particular attention to the flight design and testing cycle, thermal and mechanical considerations, space compatible materials, and high power operation. A primary focus of the course will be single, dual and shaped reflector designs including feed network topologies. Several horn antenna designs including corrugated and multimode horns will be covered as well as feed network components. A variety of other antennas including helices, patches, and arrays will be discussed for applications including: Global Navigation Satellite System (GNSS); Tracking, Telemetry and Command (TT&C); isoflux; smallsat and cubesat antennas.

Prerequisite(s): An undergraduate- or graduate-level introductory antenna systems course, or with approval of the instructor.

Instructor(s): Bray

675.761 Reliability Engineering and Analysis for Space Missions VL

This course covers the principal methods of reliability analysis as it pertains to space systems. These seek to help development teams to anticipate and find design and operational issues. Basic analytical techniques covered include fault tree and reliability block diagrams; Failure Mode and Effects Analysis (FMEA); event tree construction and evaluation; and reliability data collection and analysis. More advanced techniques of risk and reliability modeling of systems include Bayesian methods and applications, estimation of rare event frequencies, uncertainty analysis and propagation methods. These methods and techniques are integrated into quantitative assessments to address hardware, software, and human reliabilities, as well as their dependencies.

Prerequisite(s): Completion of 675.600 Systems Engineering for Space and 675.601 Fundamentals of Engineering Space Systems I, or with approval of the instructor.

Instructor(s): Smith

675.768 Spacecraft Systems Integration & Test

This course introduces students to the fundamental principles of developing Integration & Test (I&T) programs for space systems. Topics covered will provide a detailed understanding with practical applications of all phases of Spacecraft I&T starting with the design input/planning phase, staffing/budget phase, subsystem and instrument integration phase, environmental testing phase, and finally the launch campaign phase in the field. Classes will be structured to provide students information exchange sessions with subject matter experts and actual practitioners within the I&T community. Students will learn about all of the Electrical and Mechanical ground support equipment needed to build a spacecraft and the importance of the paperwork and processes used throughout all phases to manage spacecraft systems I&T.

Prerequisite(s): 675.600 Systems Engineering for Space and 675.601 Fundamentals of Engineering Space Systems I, or with approval of the instructor.

Instructor(s): Dolbow, Lang

675.771 Space Mission Design and Navigation VL

Critical to the development of space missions is the careful analysis and design of the desired path of the space vehicle (mission design) and the determination of the space vehicle's actual state vector (navigation). This course presents these two topics in an integrated manner, intended to provide space engineering professionals with a technical understanding of these complex subjects. Mission Design topics include kinematics, Kepler's Laws, Newton's Law of gravitation, modeling of several fidelity levels of spacecraft trajectory dynamics, and optimization of objective functions and satisfaction of constraints. Navigation topics include dynamics and measurement model formulations, standard estimation algorithms such as the Kalman filter and batch estimators, and performance analysis. This course will focus on the theory from a mathematical derivation perspective, example problems, and practical implementation considerations. This is an algorithm intensive course and students are expected to be comfortable with the following: MATLAB programming (or equivalent), Linear Algebra, Linear Systems, Differential Equations, basic Probability concepts, and Calculus.

Prerequisite(s): Completion of 675.600 Systems Engineering for Space and 675.601 Fundamentals of Engineering for Space Systems I, or with approval of the instructor.

Instructor(s): Mitch, Scott

675.800 Directed Studies in Space Systems Engineering

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(s): The Independent Study/Project Form (ep.jhu.edu/student-forms) must be completed and approved prior to registration.

Course Note(s): This course is open only to candidates in the Master of Science in Space Systems Engineering program.

DATA SCIENCE

See also the Applied and Computational Mathematics (625.xxx) and the Computer Science (605.xxx) sections of the course descriptions.

685.621 Algorithms for Data Science

This follow-on course to data structures (e.g., 605.202 Data Structures) providing 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 data science. Topics include advanced data structures for data science (tree structures, disjoint set data structures), algorithm analysis and computational complexity (recurrence relations, big-O notation, introduction to complexity classes (P, NP and NP-completeness)), data transformations (FFTs, principal component analysis), design paradigms (divide and conquer, greedy heuristic, dynamic programming), and graph algorithms (depth-first and breadth-first search, ordered and unordered trees). Advanced topics are selected from among the following: approximation algorithms, computational geometry, data preprocessing methods, data analysis, linear programming, multi-threaded algorithms, matrix operations, and statistical learning methods. The course will draw on applications from Data Science.

Course Prerequisite(s): 605.202 Data Structures or equivalent, and 605.201 Introduction to Programming Using Java or equivalent. 605.203 Discrete Mathematics or equivalent is recommended.

Course Note(s): This required foundation course must be taken before other 605.xxx courses in the degree. This course does not satisfy the foundation course requirement for Bioinformatics, Computer Science, or Cybersecurity. Students can only earn credit for one of 605.620, 605.621, or 685.621.

Instructor(s): Chen and Rodriguez

685.648 Data Science

This course will cover the core concepts and skills in the emerging field of data science. These include problem identification and communication, probability, statistical inference, visualization, extract/transform/load (ETL), exploratory data analysis (EDA), linear and logistic regression, model evaluation and various machine learning algorithms such as random forests, k-means clustering, and association rules. The course recognizes that although data science uses machine learning techniques, it is not synonymous with machine learning. The course emphasizes an understanding of both data (through the use of systems theory, probability, and simulation) and algorithms (through the use of synthetic and real data sets). The guiding principles throughout are communication and reproducibility. The course is geared towards giving students direct experience in solving the programming and analytical challenges associated with data science.

Prerequisite(s): Programming experience in Python is recommended.

Instructor(s): Butcher

685.795 Capstone Project in Data Science

This course permits graduate students in data 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.

Prerequisite(s): Seven data science graduate courses including two courses numbered 605.7xx or 625.7xx or admission to the post-master's certificate program. Students must also have permission of a faculty mentor, the student's academic advisor, and the program chair.

Course Note(s): Students may not receive credit for both 685.802 Independent Study in Data Science II and 685.795.

685.801 Independent Study in Data Science I

This course permits graduate students in data 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 suitable to be submitted for publication.

Prerequisite(s): Seven data science graduate courses including two courses numbered 605.7xx or 625.7xx or admission to the post-master's certificate program. Students must also have permission of a faculty mentor, the student's academic advisor, and the program chair.

685.802 Independent Study in Data Science II

Students wishing to take a second independent study in data science should sign up for this course.

Prerequisite(s): 605.801 Independent Study in Data Science I and permission of a faculty mentor, the student's academic advisor, and the program chair.

Course Note(s): Students may not receive credit for both 685.795 Capstone Project in Data Science and 685.802.

CYBERSECURITY

695.601 Foundations of Information Assurance

This course surveys the broad fields of enterprise security and privacy, concentrating on the nature of enterprise security requirements by identifying threats to enterprise information technology (IT) systems, access control and open systems, and system and product evaluation criteria. Risk management and policy considerations are examined with respect to the technical nature of enterprise security as represented by government guidance and regulations to support information confidentiality, integrity and availability. The course develops the student's ability to assess enterprise security risk and to formulate technical recommendations in the areas of hardware and software. Aspects of security-related topics to be discussed include network security, cryptography, IT technology issues, and database security. The course addresses evolving Internet, Intranet, and Extranet security issues that affect enterprise security. Additional topics include access control (hardware and software), communications security, and the proper use of system software (operating system and utilities). The course addresses the social and legal problems of individual privacy in an information processing environment, as well as the computer "crime" potential of such systems. The class examines several data encryption algorithms.

Course Note(s): This course can be taken before or after 605.621 Foundations of Algorithms. It must be taken before other courses in the degree.

Instructor(s): Ambuel, Garonzik, Heinbuch, Podell, Tarr, Valenta, Young

695.611 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(s): 605.202 Data Structures; 695.601 Foundations of Information Assurance, a basic understanding and working knowledge of computer systems, and access to Intel-based PC hosting a Microsoft Windows environment.

Instructor(s): Kalb

695.612 Operating Systems Security

This course covers both the fundamentals and advanced topics in operating system (OS) security. Access control mechanisms (e.g., SACL/DACL), memory protections, and interprocess communications mechanisms will be studied. Students will learn the current state-of-the-art OS-level mechanisms and policies designed to help protect systems against sophisticated attacks. In addition, advanced persistent threats, including rootkits and malware, as well as various protection mechanisms designed to thwart these types of malicious activities, will be studied. Advanced kernel debugging techniques will be applied to understand the underlying protection mechanisms and analyze the malicious software. Students will learn both hardware and software mechanisms designed to protect the OS (e.g., NX/ASLR/SMEP/SMAP). The course will use virtual machines to study traditional OS environments on modern 64-bit systems (e.g., Windows, Linux, and macOS), as well as modern mobile operating systems (e.g., iOS and Android).

Prerequisite(s): Familiarity with operating system concepts.

Instructor(s): McGuire

695.614 Security Engineering

This course covers cybersecurity systems engineering principles of design. Students will learn the foundational and timeless principles of cybersecurity design and engineering. They will learn why theories of security come from theories of insecurity, the important role of failure and reliability in security, the fundamentals of cybersecurity risk assessment, the building blocks of cybersecurity, intrusion detection design, and advanced topics like cybersecurity situational understanding and command and control. The course develops the student's ability to understand the nature and source of risk to a system, prioritize those risks, and then develop a security architecture that addresses those risks in a holistic manner, effectively employing the building blocks of cybersecurity systems–prevention, detection, reaction, and attack-tolerance. The student will learn to think like a cyber-attacker so that they can better design and operate cybersecurity systems. Students will attain the skill of systematically approaching cybersecurity from the top down and the bottom up and have confidence that their system designs will be effective at addressing the full spectrum of the cyber-attack space. The course also addresses how the cybersecurity attack and defense landscape will evolve so that the student is not simply ready to address today's problems, but can quickly adapt and prepare for tomorrow's. The course is relevant at any stage in a student's curriculum: whether at the beginning to enable the student to understand the big picture before diving into the details, at the end as a capstone, or in the middle to integrate the skills learned to date.

Prerequisite(s): 695.601 Foundations of Information Assurance.

Instructor(s): Saydjari

695.615 Cyber Physical System Security

The age of cyber physical systems (CPS) has officially begun. Not long ago, these systems were separated into distinct domains, cyber and physical. Today, the rigid dichotomy between domains no longer exists. Cars have programmable interfaces, unmanned aerial vehicles (UAVs) roam the skies, and critical infrastructure and medical devices are now fully reliant on computer control. With the increased use of CPS and the parallel rise in cyber-attack capabilities, it is imperative that new methods for securing these systems be developed. This course will investigate key concepts behind CPS including control systems, protocol analysis, behavioral modeling, and intrusion detection system (IDS) development. The course will comprise theory, computation, and projects to better enhance student learning and engagement, beginning with the mathematics of continuous and digital control systems and then focusing on the complex world of CPS, where general overviews for the different domains (industrial control, transportation, medical devices, etc.) are complemented with detailed case studies (Siemens ICS & ArduPilot UAVs). Several advanced topics, including behavioral analysis and resilient CPS, will be introduced. Students will complete several projects, both exploiting security vulnerabilities and developing security solutions for UAVs and industrial controllers.

Prerequisite(s): Knowledge of IP addresses and packets, matrix algebra, and Windows and Linux operating systems.

Instructor(s): Birnbaum

695.621 Public Key Infrastructure and Managing E-Security

This course describes public key technology and related security management issues in the context of the Secure Cyberspace Grand Challenge of the National Academy of Engineering. Course materials explain Public Key Infrastructure (PKI) components and how the various components support e-business and strong security services. The course includes the basics of public key technology; the role of digital certificates; a case study that emphasizes the content and importance of certificate policy and certification practices; identification challenges and the current status of the National Strategy for Trusted Identities in Cyberspace; and essential aspects of the key management life-cycle processes that incorporate the most recent research papers of the National Institute of Standards and Technology. Students will examine PKI capabilities and digital signatures in the context of the business environment, including applicable laws and regulations. The course also presents the essential elements for PKI implementation, including planning, the state of standards, and interoperability challenges. The course also provides an opportunity for students to tailor the course to meet specific cybersecurity interests with regard to PKI and participate in discussions with their peers on contemporary cybersecurity topics.

Instructor(s): Mitchel

695.622 Web Security

This course examines issues associated with making web applications secure. The principal focus is on server-side security such as CGIsecurity, proper server configuration, and firewalls. The course also investigates the protection of connections between a client and server using current encryption protocols (e.g., SSL/TLS) as well discussing the related attacks on these protocols (e.g., Heartbleed, CRIME, etc.). The course also investigates keeping certain data private from the server system (e.g., via third-party transaction protocols like SET, or PCI DSS standard). Elementary Number Theory will be reviewed. Finally, the course explores client-side vulnerabilities associated with browsing the web, such as system penetration, information breach, identity theft, and denial-of-service attacks. Related topics such as malicious e-mails, web bugs, spyware,and software security are also discussed. Labs and various server-side demonstrations enable students to probe more deeply into security issues and to develop and test potential solutions. Basic knowledge of operating systems is recommended. Students will download and install a Virtual Machine to be used in the course.

Prerequisite(s): 605.202 Data Structures; 605.612 Operating Systems or basic knowledge of operating systems is recommended.

Instructor(s): Kovba, McGuire, Young

695.641 Cryptology

This course provides an introduction to the principles and practice of contemporary cryptology. It begins with a brief survey of classical cryptographic techniques that influenced the modern development of cryptology. The course then focuses on contemporary work: symmetric block ciphers and the Advanced Encryption Standard, public key cryptosystems, digital signatures, authentication protocols, cryptographic hash functions, and cryptographic protocols and their applications. Pertinent ideas from complexity theory and computational number theory, which provide the foundation for much of the contemporary work in cryptology, are introduced as needed throughout the course.

Course Note(s): This course should be taken after the other two required foundation courses and before any other courses in the Analysis track.

Instructor(s): May, Zaret

695.642 Intrusion Detection

This course explores the use of intrusion detection systems (IDS) as part of an organization's overall security posture. A variety of approaches, models, and algorithms along with the practical concerns of deploying IDS in an enterprise environment will be discussed. Topics include the history of IDS, anomaly and misuse detection for both host and network environments, and policy and legal issues surrounding the use of IDS. The use of ROC (receiver operating characteristic) curves to discuss false positives and missed detection tradeoffs as well as discussion of current research topics will provide a comprehensive understanding of when and how IDS can complement host and network security. TCPDump and Snort will be used in student assignments to collect and analyze potential attacks.

Prerequisite(s): 605.202 Data Structures; 605.101 Introduction to Python or knowledge of Python.

Instructor(s): Gates, Longstaff

695.643 Introduction to Ethical Hacking

This course exposes students to the world of computer hacking. The primary goal is to give students an understanding of how vulnerable systems can be attacked as a means to motivate how they might be better defended. The class takes a systems engineering view of hacking and emphasizes practical exposure via hands-on assignments. Students are expected to use a computer that will remain off all networks while they complete assignments.

Prerequisite(s): 695.601 Foundations of Information Assurance and one of 635.611 Principles of Network Engineering or 605.671 Principles of Data Communications Networks.

Course Note(s): Homework assignments will include programming.

Instructor(s): Crossland, Kovba, Smeltzer

695.711 Java Security VL

This course examines security topics in the context of the Java language with emphasis on security services such as confidentiality, integrity, authentication, access control, and non-repudiation. Specific topics include mobile code, mechanisms for building "sandboxes" (e.g., class loaders, namespaces, bytecode verification, access controllers, protection domains, policy files), symmetric and asymmetric data encryption, hashing, digital certificates, signature and MAC generation/verification, code signing, key management, SSL, and object-level protection. Various supporting APIs are also considered, including the Java Cryptography Architecture (JCA) and Java Cryptography Extension (JCE). Security APIs for XML and web services, such as XML Signature and XML Encryption, Security Assertions Markup Language (SAML), and Extensible Access Control Markup Language (XACML), are also surveyed. The course includes multiple programming assignments and a project.

Prerequisite(s): 605.681 Principles of Enterprise Web Development or equivalent. Basic knowledge of XML. 695.601 Foundations of Information Assurance or 695.622 Web Security would be helpful but is not required.

Instructor(s): Ceesay

695.712 Authentication Technologies in Cybersecurity

Authentication technologies in cybersecurity play an important role in identification, authentication, authorization, and non-repudiation of an entity. The authentication process in cybersecurity, which is considered to be one of the weakest links in computer security today, takes many forms as new technologies such as cloud computing, mobile devices, biometrics, PKI, and wireless are implemented. Authentication is the security process that validates the claimed identity of an entity, relying on one or more characteristics bound to that entity. An entity can be, but is not limited to, software, firmware, physical devices, and humans. The course explores the underlying technology, the role of multi-factor authentication in cyber security, evaluation of authentication processes, and the practical issues of authentication. Several different categories and processes of authentication will be explored along with password cracking techniques, key logging, phishing, and man-in-the-middle attacks. Examples of authentication breaches and ethical hacking techniques will be explored to examine the current technologies and how they can be compromised. Case studies of authentication system implementation and their security breaches are presented. Federated authentication process over different network protocols, topologies, and solutions will be addressed. Related background is developed as needed, allowing students to gain a rich understanding of authentication techniques and the requirements for using them in a secure environment including systems, networks, and the Internet. Students will present a research project that reflects an understanding of key issues in authentication.

Prerequisite(s): 605.202 Data Structures; 695.601 Foundations of Information Assurance. 695.621 Public Key Infrastructure and Managing E-Security is recommended.

695.721 Network Security

This course covers concepts and issues pertaining to network security and network security architecture and evolving virtualization and related cloud computing security architecture. Topics include mini-cases to develop a network security context. For example, we will assess the NIST (National Institute of Standards and Technology) unified information security framework. This framework is supported by information security standards and guidance, such as a risk management framework (RMF) and continuous monitoring (CM) process. Applied cryptography and information security—encryption algorithms, hash algorithms, message integrity checks, digital signatures, security assessment and authentication, authorization and accounting (AAA), security association, and security key management (generation, distribution, and renewal)—are discussed with consideration given to emerging cryptographic trends, such as the evolution and adoption of NSA's (National Security Agency's) Suite B cryptography. This course presents network and network security architecture viewpoints for selected security issues, including various security mechanisms, different layers of wired/wireless security protocols, different types of security attacks and threats and their countermeasures or mitigation, Next Generation Network (NGN) security architecture that supports the merging of wired and wireless communications, and Internet Protocol version 6 implementation and transition. The course concludes with more comprehensive cases that consider network security aspects of virtualization and cloud computing architecture.

Prerequisite(s): 605.202 Data Structures; 695.601 Foundations of Information Assurance and 605.671 Principles of Data Communications Networks or 635.611 Principles of Network Engineering.

Instructor(s): Heinbuch, Podell

695.741 Information Assurance Analysis

This course provides students with an overview of analysis as it applies to information assurance. Analysis is a fundamental part of the information assurance process, and effective analysis informs policy, software development, network operations, and criminal investigations. To enable students to perform effective analysis, the focus of the course is on the analysis process and approach rather than on specific tools. Topics include the collection, use, and presentation of data from a variety of sources (e.g., raw network traffic data, traffic summary records, and log data collected from servers and firewalls). These data are used by a variety of analytical techniques, such as collection approach evaluation, population estimation, hypothesis testing, experiment construction and evaluation, and constructing evidence chains for forensic analysis. Students will construct and critique an analytical architecture, construct security experiments, and retroactively analyze events. The course will also cover selected non-technical ramifications of data collection and analysis, including anonymity, privacy, and legal constraints.

Prerequisite(s): 695.601 Foundations of Information Assurance. Familiarity with basic statistical analysis. 695.642 Intrusion Detection or 695.611 Embedded Computer Systems-Vulnerabilities, Intrusions, and Protection Mechanisms is recommended.

Instructor(s): Anthony, Crossfield

695.742 Digital Forensics Technologies and Techniques

Digital forensics focuses on the acquisition, identification, attribution, and analysis of digital evidence of an event occurring in a computer or network. This course provides a broader scientific understanding of the technologies and techniques used to perform digital forensics. In particular, various signature extraction techniques, detection, classification, and retrieval of forensically interesting patterns will be introduced. This will be complemented by studying fundamental concepts of data processing technologies like compression, watermarking, steganography, cryptography, and multiresolution analysis. Emerging standards along with issues driving the changing nature of this topic will be explored. Anti-forensic techniques that are used to counter forensic analysis will also be covered. Students will be exposed to relevant theory, programming practice, case studies, and contemporary literature on the subject.

Prerequisite(s): 605.612 Operating Systems.

Instructor(s): Ahmed

695.744 Reverse Engineering and Vulnerability Analysis

This course covers both the art and science of discovering software vulnerabilities. Beginning with the foundational techniques used to analyze both source and binary code, the course will examine current threats and discuss the actions needed to prevent attackers from taking advantage of both known and unknown vulnerabilities. The course will cover passive and active reverse engineering techniques in order to discover and categorize software vulnerabilities, create patches and workarounds to better secure the system, and describe security solutions that provide protection from an adversary attempting to exploit the vulnerabilities. Techniques covered include the use of static analysis, dynamic reverse engineering tools, and fault injection via fuzzing to better understand and improve the security of software.

Instructor(s): McGuire

695.749 Cyber Exercise

Students will learn about the nature and purpose of cyber exercises and their role in training and assessing people, teams, technology, and procedures. During the course of the semester, students will design a cyber exercise that meets the specific needs of their organization. At the conclusion of the class, students will have a model template they can use to design, build, and execute their own exercise.

Instructor(s): Rosenberg

695.791 Information Assurance Architectures and Technologies

This course explores concepts and issues pertaining to information assurance architectures (IAA) and technologies, such as layered security architecture guidance and cases from the National Institute of Standards and Technology (NIST) and NIST Cybersecurity Center of Excellence (NCCoE); cryptographic commercial issues and evolving federal guidance; hypervisor and cloud computing security architecture; and IAA and technologies applications. Topics include critical infrastructure protection and Comprehensive National Cybersecurity Initiative (CNCI) Trusted Internet Connections (TIC) 2.0 multi-agency security information management (SIM) and selected security analytics issues. Commercial IAA examples of network security architecture and security analytics are also discussed for evolving enterprise mobility issues. The relationships of IAA and technologies with selected multi-tier architectures are discussed for applications such as enterprise risk management; security for virtualized environments; systems security engineering for services; and mobile device security. IAA multi-tier architecture issues are illustrated with cases, such as the NIST NCCoE use cases for Data Integrity: Recovering from Ransomware and Other Destructive Events; Access Rights Management for the Financial Services Sector; Situational Awareness for Electric Utilities; and Derived Personal Identity Verification (PIV) Credentials. Selected large-scale programs are discussed, such as enterprise risk management for the Federal Aviation Administration (FAA) Air Traffic Modernization process; and NIST Smart Grid Cybersecurity Strategy, Architecture, and High-Level Requirements.

Prerequisite(s): 605.202 Data Structures; 695.601 Foundations of Information Assurance or equivalent, and 605.671 Principles of Data Communications Networks or 635.611 Principles of Network Engineering.

Instructor(s): Garonzik, Podell

695.801 Independent Study in Cybersecurity I

This course permits graduate students in cybersecurity 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.

Prerequisite(s): Seven Cybersecurity graduate courses including the foundation courses, three track-focused area courses, and two courses numbered at the 700 level or admission to the post-master's certificate program. Students must also have permission from the instructor.

695.802 Independent Study in Cybersecurity II

Students wishing to take a second independent study in Cybersecurity should sign up for this course.

Prerequisite(s): 695.801 Independent Study in Cybersecurity I and permission of a faculty mentor, the student's academic advisor, and the program chair.

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EQUAL OPPORTUNITY/NONDISCRIMINATORY POLICY AS TO STUDENTS

The Johns Hopkins University is committed to recruiting, supporting, and fostering a diverse community of outstanding faculty, staff, and students. As such, Johns Hopkins does not discriminate on the basis of gender, marital status, pregnancy, race, color, ethnicity, national origin, age, disability, religion, sexual orientation, gender identity or expression, veteran status, or other legally protected characteristic in any student program or activity administered by the university or with regard to admission or employment. Defense Department discrimination in Reserve Officer Training Corps (ROTC) programs on the basis of sexual orientation conflicts with this university policy. The university continues its ROTC program but encourages a change in the Defense Department Policy.

Questions regarding Title VI, Title IX, and Section 504 should be referred to the Office of Institutional Equity, 410-516-8075.

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Notice is hereby given that the Johns Hopkins Engineering for Professionals program complies with the provisions of the Family Educational Rights and Privacy Act (FERPA) of 1974 (P.L. 93-380), as amended, and regulations promulgated thereunder. FERPA affords eligible students certain rights with respect to their education records. These rights are as follows: (1) The right to inspect and review the student's education records within 54 days of the day the university receives a request for access. Students should submit to the Registrar written requests that identify the record(s) they wish to inspect. The Registrar will make arrangements for access and notify the student of the time and place where the records may be inspected. If the records are not maintained by the Registrar, the student will be advised of the correct official to whom the request should be addressed. (2) The right to request amendment of education records that the student believes are inaccurate or misleading. Students should write to the university official responsible for the record they want changed and specify why it is inaccurate or misleading. If the university decides not to amend the records as requested by the student, the student will be notified of the decision and advised of his or her right to a hearing regarding the request for amendment. Additional information regarding the hearing procedures will be provided to the student when notified of the right to a hearing. (3) The right to consent to disclosures of personally identifiable information contained in the student's education records, except to the extent that FERPA authorizes disclosures without consent. Disclosure without consent is granted to school officials with legitimate educational interests. A school official is a person employed by the university in an administrative, supervisory, academic or research, or support staff position (including law enforcement unit personnel and health staff); a person serving on the board of trustees; or a student serving on an official committee, such as a disciplinary or grievance committee, or assisting another school official in performing his or her tasks. A school official has a legitimate educational interest if the official needs to review an education record in order to fulfill his or her professional responsibility. (4) The right to file a complaint with the US Department of Education concerning alleged failures by the university to comply with the requirements of FERPA.

The name and address of the office that administers FERPA is:

Family Policy Compliance Office
US Department of Education
400 Maryland Avenue S.W.
Washington, DC 20202-4605

AMERICANS WITH DISABILITIES ACT POLICY

Johns Hopkins University is committed to ensuring that all qualified individuals with disabilities have the opportunity to participate in educational programs and services on an equal basis. The university supports the integration of all qualified individuals into the programs of the university and is committed to full compliance with all laws regarding equal opportunity for all students with a disability. At the university, students, Student Disability Services (SDS), faculty, academic deans and department chairs, and the Director, ADA Compliance, all play a joint role in promoting equal access to campus facilities and programs.

Under the Americans with Disabilities Act of 1990, as amended, and Section 504 of the Rehabilitation Act, all qualified students with a disability (as defined under the law) are eligible for reasonable accommodations or modifications in the academic environment that enable the qualified individual to enjoy equal access to the university's programs, services, or activities. Programs and activities must be provided in the most integrated setting appropriate. The university is not required to provide any aid or service that would result in a fundamental alteration to the nature of the program.

SDS and the Director of ADA Compliance work together to provide disability consultation, advocacy, and the coordination of support services and accommodations for all qualified students with disabilities. Services and accommodations are determined individually based on disability documentation. In order to receive services, students must disclose their disability and be found eligible for an accommodation.

The university is committed to promoting the full participation of all qualified students with disabilities in all aspects of campus life. Students with disabilities are required to meet the same academic standards as other students at the university. It is only through a student's voluntary disclosure of their disability and request for accommodations that the university can support disability needs. Students that do not voluntarily disclose their disability and request accommodations are not eligible for services.

Students who have a disability and wish to make a request for disability-related accommodations or services must do so through the appropriate disability accommodation process. Each student must submit their documentation along with an intake form in order to apply for services. Students are encouraged to register prior to arrival on campus for the upcoming semester. Once eligibility is determined, appropriate accommodations based on the approved documentation are put in place. Accommodations are determined on a case-by-case basis.

Undergraduate students should contact:

Student Disability Services
385 Garland Hall
3400 N. Charles St.
Baltimore, MD 21218
Phone: 410-516-4720
Website: https://studentaffairs.jhu.edu/disabilities/

Graduate students should contact:

Disability Services Coordinator
Johns Hopkins Engineering for Professionals
Wyman Park Building
3400 N. Charles Street
Baltimore, MD 21218
Phone: 410-516-2306
E-mail: ep-disability-svcs@jhu.edu
Website: https://ep.jhu.edu/student-services/other-services/disability-services

SEXUAL HARASSMENT PREVENTION AND RESOLUTION POLICY

PREAMBLE

The Johns Hopkins University is committed to providing its staff, faculty, and students the opportunity to pursue excellence in their academic and professional endeavors. This can exist only when each member of our community is assured an atmosphere of mutual respect, one in which they are judged solely on criteria related to academic or job performance. The university is committed to providing such an environment, free from all forms of harassment and discrimination. Each member of the community is responsible for fostering mutual respect, for being familiar with this policy, and for refraining from conduct that violates this policy.

Sexual harassment, whether between people of different sexes or the same sex, is defined to include, but is not limited to, unwelcome sexual advances, requests for sexual favors, and other behavior of a sexual nature when:

1. Submission to such conduct is made implicitly or explicitly a term or condition of an individual's employment or participation in an educational program
2. Submission to or rejection of such conduct by an individual is used as the basis for personnel decisions or for academic evaluation or advancement
3. Such conduct has the purpose or effect of unreasonably interfering with an individual's work or academic performance or creates an intimidating, hostile, or offensive working or educational environment

Fundamental to the university's purpose is the free and open exchange of ideas. It is not, therefore, the university's purpose, in promulgating this policy, to inhibit free speech or the free communication of ideas by members of the academic community.

POLICY

The university will not tolerate sexual harassment, a form of discrimination, a violation of federal and state law, and a serious violation of university policy. In accordance with its educational mission, the university works to educate its community regarding sexual harassment. The university encourages individuals to report incidents of sexual harassment and provides a network of confidential consultants by which individuals can report complaints of sexual harassment. The means by which complaints are resolved can range from informal to formal.

The university encourages reporting of all perceived incidents of sexual harassment, regardless of who the alleged offender may be. Individuals who either believe they have become the victim of sexual harassment or have witnessed sexual harassment should discuss their concerns with any member of the Sexual Harassment Prevention and Resolution system. Complainants are assured that problems of this nature will be treated in a confidential manner, subject to the university's legal obligation to respond appropriately to any and all allegations of sexual harassment.

The university prohibits acts of reprisal against anyone involved in lodging a complaint of sexual harassment. Conversely, the university considers filing intentionally false reports of sexual harassment a violation of this policy.

The university will promptly respond to all complaints of sexual harassment. When necessary, the university will institute disciplinary proceedings against the offending individual, which may result in a range of sanctions, up to and including termination of university affiliation.

Complaints of sexual harassment may be brought to Susan Boswell, Dean of Student Life, 410-516-8208; Ray Gillian, Vice Provost for Institutional Equity; or Caroline Laguerre-Brown, Director of Equity Compliance and Education, 410-516-8075.

UNIVERSITY ALCOHOL AND DRUG POLICY FOR STUDENTS

In keeping with its basic mission, the university recognizes that its primary response to issues of alcohol and drug abuse must be through educational programs, as well as through intervention and treatment efforts. To that end, the university provides appropriate programs and efforts throughout the year. The brochure "Maintaining a Drug-Free Environment: The Hopkins Commitment" is distributed annually to all faculty, students, and staff of the Johns Hopkins University, and copies are available on request from the offices of the Faculty and Staff Assistance Program, 4 East 33rd Street, Baltimore, MD 21218, 410-516-3800; or at the Counseling and Student Development Center located on the Homewood Campus, 410-516-8270.

POLICY ON POSSESSION OF FIREARMS ON UNIVERSITY PREMISES

Possessing, wearing, carrying, transporting, or using a firearm or pellet weapon is strictly forbidden on university premises. This prohibition also extends to any person who may have acquired a government-issued permit or license. Violation of this regulation will result in disciplinary action and sanctions up to and including expulsion in the case of students, or termination of employment in the case of employees. Disciplinary action for violations of this regulation will be the responsibility of the divisional student affairs officer, dean or director, or the vice president for human resources, as may be appropriate, in accordance with applicable procedures. Any questions regarding this policy, including the granting of exceptions for law enforcement officers and for persons acting under the supervision of authorized university personnel, should be addressed to the appropriate chief campus security officer.

CAMPUS SECURITY ACT NOTICE

In accordance with the Crime Awareness and Campus Security Act of 1990 (P.L. 102-26), as amended, and the regulations promulgated thereunder, the university issues its Annual Security Report that describes the security services at each of the university's divisions and reports crime statistics for each of the campuses. The report is published online at http://security.jhu.edu/. Copies of the report are available from the university's Security Department, 14 Shriver Hall, 3400 North Charles Street, Baltimore, MD 21218-2689, 410-516-4600.

PHOTOGRAPH AND FILM RIGHTS POLICY

The Johns Hopkins University reserves the right from time to time to film or take photographs of faculty, staff, and students engaged in teaching, research, clinical practices, and other activities, as well as casual and portrait photography or film. These photographs and films will be used in such publications as catalogs, posters, advertisements, recruitment and development materials, as well as on the university's website, for various videos, or for distribution to local, state, or national media for promotional purposes. Classes will be photographed only with the permission of the faculty member.

Such photographs and film—including digital media—will be kept in the files and archives of The Johns Hopkins University and remain available for use by the university without time limitations or restrictions. Faculty, students, and staff are made aware by virtue of this policy that the university reserves the right to alter photography and film for creative purposes.

Faculty, students, and staff who do not want their photographs used in the manner(s) described in this policy statement should contact the Office of Communications and Public Affairs. Faculty and students are advised that persons in public places are deemed by law to have no expectation of privacy and are subject to being photographed by third parties. The Johns Hopkins University has no control over the use of photographs or film taken by third parties, including without limitation the news media covering university activities.

RETURN OF TITLE IV FUNDS POLICY

The Financial Aid Office is required by federal statute to recalculate federal financial aid eligibility for students who withdraw, drop out, are dismissed, or take a leave of absence prior to completing sixty percent of a payment period or term. The federal Title IV financial aid programs must be recalculated in these situations. If a student leaves the institution prior to completing sixty percent of a payment period or term, the Financial Aid Office recalculates eligibility for Title IV funds. Recalculation is based on the percentage of earned aid using the following federal return of Title IV funds formula: Percentage of payment period or term completed = the number of days completed up to the withdrawal date divided by the total days in the payment period or term. (Any break of 5 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: Aid to be returned = (one hundred percent of the aid that could be disbursed minus the percentage of earned aid) multiplied by 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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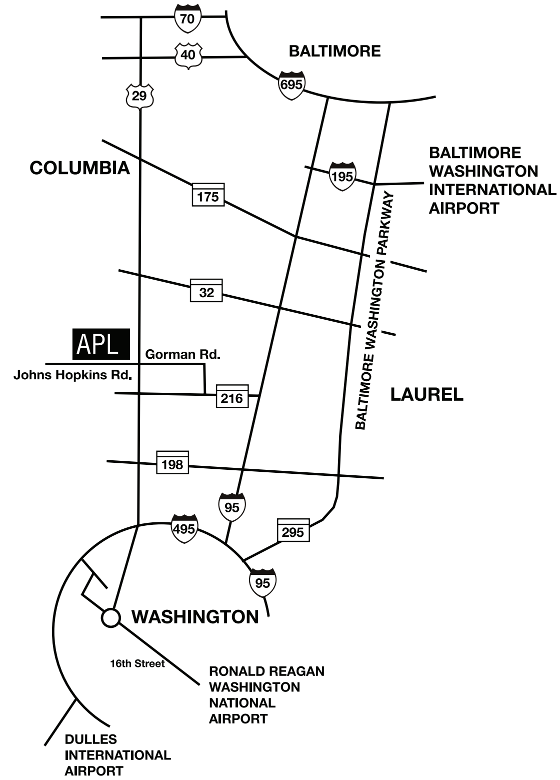
DIRECTIONS AND MAPS

APPLIED PHYSICS LABORATORY

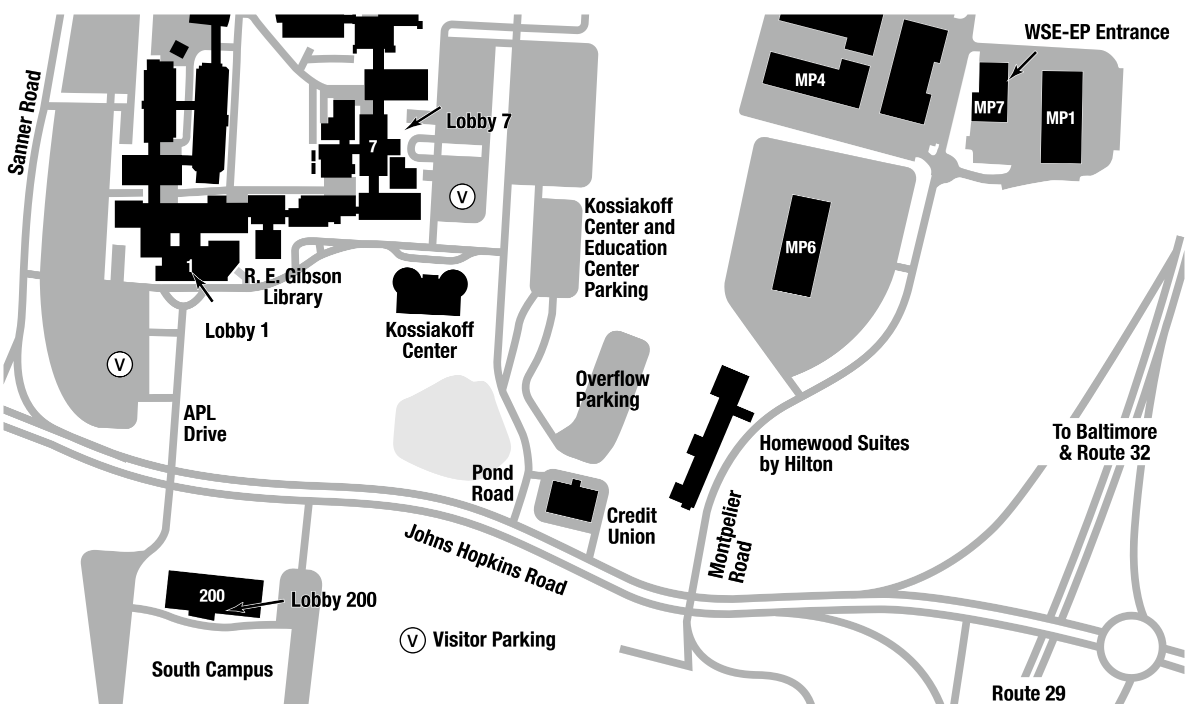
Kossiakoff Center, 11100 Johns Hopkins Road, Room K215, Laurel, MD 20723-6099
Montpelier 7 (MP7), 7710 Montpelier Road, Laurel, MD 20723-6099
240-228-6510



From Baltimore and I-95 (southbound): Take I-95 South from the Baltimore Beltway (I-695) intersection. Go 13 miles and take the Columbia exit (MD Route 32 West). Go 2.5 miles and take the Washington DC, exit (US Route 29 South). Go 1.5 miles and take the Johns Hopkins Road exit. To go to the Kossiakoff Center, go about 0.5 mile, turn right onto Pond Road, and follow the signs to the Kossiakoff Center parking on the lower lot. To go to Montpelier 7 (MP7), turn right onto Montpelier Road and then turn right into the MP7 parking lot.

From Washington and I-95 (northbound): Take I-95 North from the Capital Beltway (I-495) toward Baltimore. Go 8 miles and take MD Route 216 West (toward Scaggsville). Go 1.2 miles and turn right onto Leishear Road. Go 0.8 mile and turn left onto Gorman Road. Go 0.7 mile and cross the traffic circle and bridge over US Route 29. The road name changes to Johns Hopkins Road. To go to the Kossiakoff Center, go about 0.5 mile, turn right onto Pond Road, and follow the signs to the Kossiakoff Center parking on the lower lot. To go to Montpelier 7 (MP7), turn right onto Montpelier Road and then turn right into the MP7 parking lot.

From US Route 29: Proceed on US 29 to the Johns Hopkins Road exits. APL is about 0.5 mile west. To go to the Kossiakoff Center, go about 0.5 mile, turn right onto Pond Road, and follow the signs to the Kossiakoff Center parking on the lower lot. To go to Montpelier 7 (MP7), turn right onto Montpelier Road and then turn right into the MP7 parking lot.



HOMEWOOD CAMPUS

JOHNS HOPKINS UNIVERSITY

3400 N. Charles Street, Baltimore, MD 21218
410-516-8000

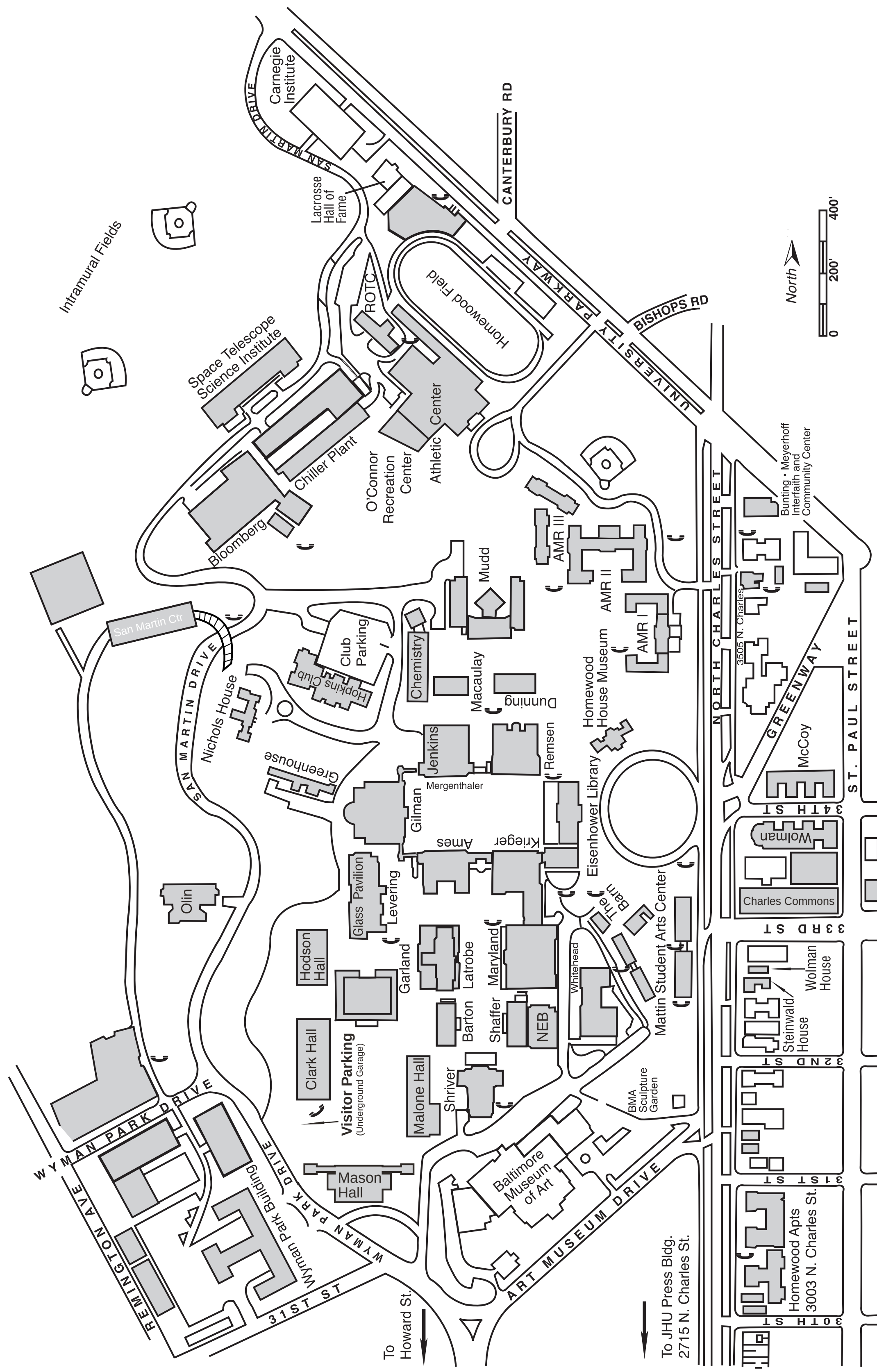
From I-95 (southbound) or from I-695 (the Baltimore Beltway): Take the beltway toward Towson to Exit 25. Take Charles Street south for about 7 miles (when Charles Street splits a block after Loyola College and Cold Spring Lane, take the right fork). As you approach the university and cross University Parkway, continue southbound, make a slight right onto the service road. After you pass the university on the right, turn right onto Art Museum Drive. Just after the Baltimore Museum of Art, bear right at the traffic island onto Wyman Park Drive. Take an almost immediate right through the university gates.

From I-95 (northbound): Exit at I-395, then take the exit to Martin Luther King Jr. Boulevard and follow the directions below.

From Maryland 295 (the Baltimore-Washington Parkway): Entering Baltimore, the parkway becomes Russell Street. Stay on Russell Street until (with Oriole Park at Camden Yards looming before you) you reach the right-hand exit marked Martin Luther King Jr. Boulevard (look carefully for this; the signs are small). Take Martin Luther King Jr. Boulevard until it ends at Howard Street (remain in one of the middle lanes of Martin Luther King Jr. Boulevard to avoid a premature forced right or left turn). Turn left at Howard Street and proceed about 2 miles. One block past 29th Street (where Howard Street becomes Art Museum Drive), turn left at the traffic island (just before the Baltimore Museum of Art) onto Wyman Park Drive. Take an almost immediate right through the university gates.

From the Jones Falls Expressway (I-83) southbound: Take the 28th Street exit to 28th Street east. Turn left on Howard Street. One block past 29th Street (where Howard Street becomes Art Museum Drive), turn left at the traffic island (just before the Baltimore Museum of Art) onto Wyman Park Drive. Take an almost immediate right through the university gates.

HOMEWOOD CAMPUS *(CONTINUED)*



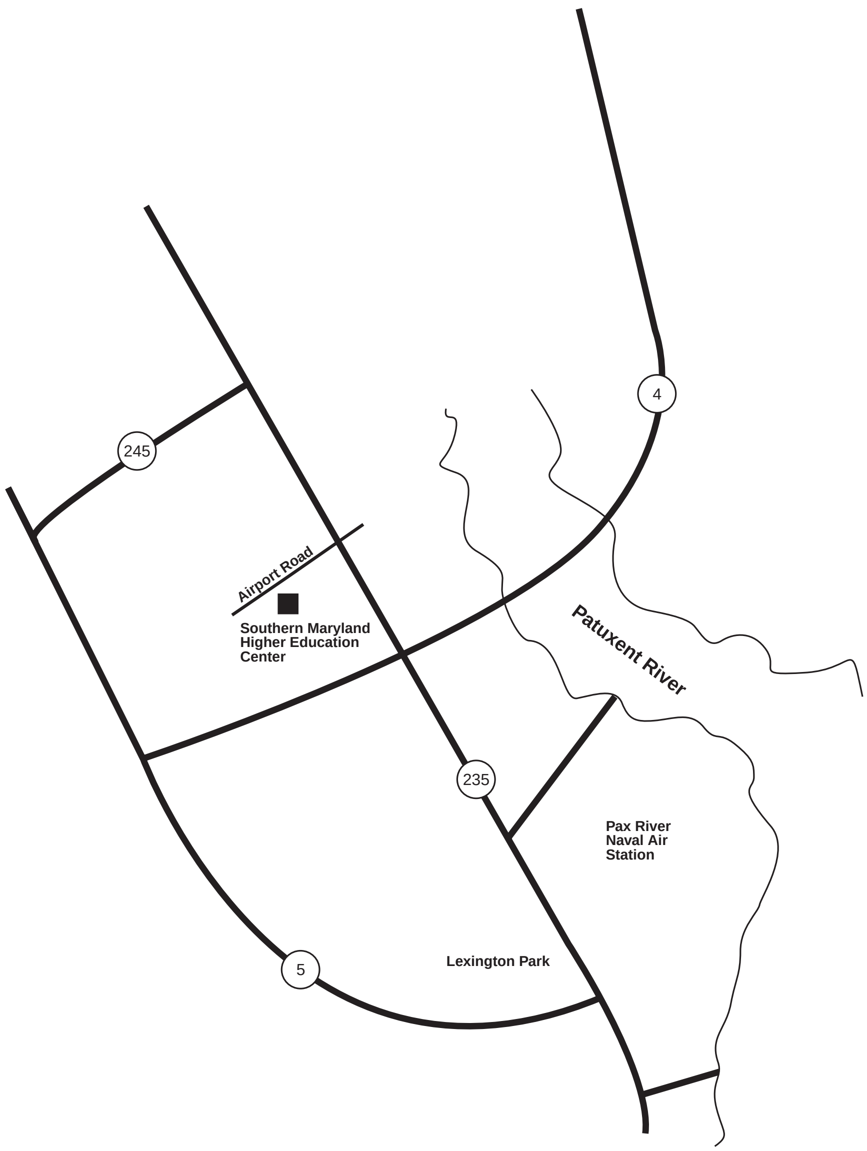
SOUTHERN MARYLAND HIGHER EDUCATION CENTER

44219 Airport Road, Wildewood Technology Park, California, MD 20619
301-737-2500

From Lexington Park: Take MD Route 235 North approximately six miles to Airport Road. Turn left on Airport Road, and go about one-quarter mile to the Southern Maryland Higher Education Center on the left.

From Calvert County: Take MD Route 4 South. At Solomons, cross the Thomas Johnson Bridge, and continue 4 miles to the stoplight at MD Route 235. Turn right on Route 235, and go north past the Wildewood Shopping Center to Airport Road. Turn left on Airport Road, and go about one-quarter mile to the Southern Maryland Higher Education Center on the left.

From Charles County: Take MD Route 5 South to St. Mary's County. About 20 miles south of Waldorf, Route 5 branches to the right toward Leonardtown, and the main four-lane road continues straight and becomes MD Route 235. Continue on Route 235 approximately 12 miles to Airport Road. Turn right on Airport Road, and go about one-quarter mile to the Southern Maryland Higher Education Center on the left.



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Baltimore, MD 21218