DEPARTMENT OF
ELECTRICAL ENGINEERING
AND
COMPUTER SCIENCE

Graduate Study Manual
2005-06
# TABLE OF CONTENTS

1. Welcome .........................................................................................................................1
   Department Administration .................................................................................................2
   General Information .............................................................................................................5
2. M.S. Program ..................................................................................................................8
   2.1. Course Requirements .........................................................................................8
   2.2. Thesis or Project Requirement ...........................................................................8
   2.3. Residency Requirement .....................................................................................9
   2.4. 588 Resident Master’s Study .............................................................................9
   2.5. Admission to Candidacy ....................................................................................9
   2.6. Final Examination ............................................................................................10
   2.7. Part-time Graduate Program ............................................................................10
3. Ph.D. Program ...............................................................................................................11
   3.1. Unit Requirements ...........................................................................................11
   3.2. Course Requirements .......................................................................................11
   3.3. Residency Requirements ..................................................................................12
   3.4. Requirement for Teaching Experience ............................................................13
   3.5. Selection of a Research Topic for the Ph.D. Dissertation ................................14
   3.6. Program of Study Evaluation ...........................................................................14
   3.7. Oral Qualifying Exam ......................................................................................14
   3.8. Admission to Candidacy ..................................................................................15
   3.9. Registration After Admission to Candidacy ....................................................16
   3.10. Dissertation ......................................................................................................16
   3.11. Final Examination ............................................................................................17
   3.12. Foreign Language Requirement .......................................................................17
   3.13. 598 – Resident Doctoral Study .......................................................................17
   3.14. Crown Family Graduate Internship Program ..................................................18
4. Programs of Study .........................................................................................................19
   4.1. Solid State and Photonics .................................................................................19
   4.2. Computer Engineering & Systems ...................................................................21
   4.3. Computing, Algorithms Engineering ................................................................23
   4.4. Cognitive Systems ...........................................................................................31
   4.5. Signals & Systems ...........................................................................................32
   4.6. Graphics & Interactive Media ..........................................................................33
5. Department Research Areas ..........................................................................................35
   New Student Sign-up List .................................................................................................38
6. Student Related Activities and Organizations ..............................................................39
7. Laboratory and Computer Facilities ............................................................................41
8. Department Faculty .......................................................................................................42
9. Detailed Course Descriptions .......................................................................................50
1. Welcome

As the Chairman of the Department of Electrical Engineering and Computer Science at the McCormick School of Engineering and Applied Science, it gives me great pleasure to welcome you to this department. The Department of Electrical Engineering and Computer Science is the largest department in the McCormick School with 53 full time faculty members, about 251 undergraduate and 162 graduate students, and many state-of-the-art laboratory facilities.

The department offers graduate degree programs in Electrical and Computer Engineering or Computer Science. Our EECS department has an internationally renowned faculty, state-of-the-art research equipment, and the considerable resources offered by a great university. We combine those advantages with an uncommon commitment to our students.

We have faculty who are Fellows of IEEE, OSA, APS, & AAAS. Several faculty members have received PYI, NYI or CAREER awards from the National Science Foundation. Two of our emeritus faculty are members of the National Academy of Engineering.

Research in our EECS department spans a wide variety of disciplines essential to the growing information technology. Our faculty are organized into six divisions:

- Solid State and Photonics
- Computer Engineering & Systems
- Computing, Algorithms & Applications
- Cognitive Systems
- Signals and Systems
- Graphics & Interactive Media

In addition, the department is involved with seven interdisciplinary research centers:

- Optimization Technology Center
- Center for Quantum Devices
- Motorola Center for Telecommunications Research
- Center for Photonic Communication and Computing
- Center for Ultra-scale Computing and Information Security
- Council on Dynamic Systems and Control
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Electrical Engineering Undergraduate Curriculum Committee:
Alan Sahakian (Chairman), Prem Kumar, Dongning Guo, Michael Honig, Manijeh Razeghi, Aggelos Katsaggelos, C. C. Lee, and an Undergraduate Student

Computer Engineering Undergraduate Curriculum Committee:
Alok Choudhary (Chairman), Yehea Ismail, Aleksandar Kuzmanovic, Chi-haur Wu, Hai Zhou, Seda Memik, and Andrew Kou

Computer Science Undergraduate Curriculum Committee:
Larry Birnbaum (Chairman), Yan Chen, Ken Forbus, Justine Cassell, Bruce Gooch, Ian Horswill, Peter Dinda, and Seda Memik

Instructional Labs Committee:
Chi-haur Wu (Chairman), Larry Henschen, Alan Sahakian, Hooman Mohseni, Jack Tumblin, Mary Phillips, and Norm Flasch (ex officio)

Computing Facilities Committee:
Peter Scheuermann (Chairman), Jorge Nocedal, Aggelos Katsaggelos, Gokhan Memik, Peter Dinda, Fabian Bustamante, Randy Berry, Ken Forbus, Pred Bundalo (ex officio), and Scott Hoover (ex officio)

Publicity, Alumni and Industrial Relations Committee:
Seng-Tiong Ho (Chairman), Fabian Bustamante, Abe Haddad, Ming Kao, Kris Hammond, Don Norman and Aggelos Katsaggelos

Teaching and External Awards Committee:
Randy Freeman (Chairman), Abe Haddad, Wei-Chung Lin, Horace Yuen, Hai Zhou, Ken Forbus, and Martin Plonus

Distinguished Seminar Committee:
Yehea Ismail (Chairman), Ming Kao, Hai Zhou, Ying Wu, Thrasos Pappas, Selim Shahriar, and Peter Dinda

Undergraduate Recruiting
Allen Taflove (Chair), Manijeh Razeghi, Robert Dick, Fabian Bustamante, Seda Memik, and Bruce Gooch

Secretary of the Faculty
Randy Freeman
This Graduate Study Manual provides detailed information about the educational opportunities in the Graduate Programs in Electrical Engineering, Computer Engineering and Computer Science. It includes descriptions of our curriculum, suggestions for course work, various options, and information about our faculty, computer facilities and student activities.

On behalf of the faculty of the Electrical Engineering and Computer Science Department, I would like to welcome you and wish you very successful and pleasant years at Northwestern University.

Christopher Riesbeck
Associate Chair for Graduate Affairs

Student Responsibilities

It is the responsibility of the student to insure that all the requirements of the Graduate School and the Department are met by the program he or she selects, that necessary examinations are properly scheduled, and that deadlines dependent on current university calendars are observed (the calendar is printed in the front of the quarterly class schedule). The current procedures and degree requirements of the EECS Graduate Programs are detailed in this document. In addition students are strongly urged to consult regularly with their faculty advisors and may consult with the Associate Chair for Graduate Affairs for any questions related to procedures and requirements.

Planning the Program of Study

Students are advised to plan their programs of study for an advanced degree before commencing such study. An initial program advisor is assigned for each student to assist with planning for the first quarters of study. Students are encouraged to find a permanent research advisor by the end of the first quarter of registration. The research advisor will be the student's primary contact with the Department for the remainder of the student's program and should be chosen to match the student's research interests (see Section 4). Each student should fill out his/her study plan on a form supplied by the Department. The study plan should be approved by the student's advisor prior to registration and updated with any program changes and grades each quarter. Should the student decide to change advisors, the old advisor and the Associate Chair for Graduate Affairs must be informed, and a new plan, at the new advisor's option, may be prepared. Graduate courses in electrical engineering, computer engineering, and related fields are described in this bulletin and the bulletin of the Graduate School.
The normal full-time program of graduate study is three units per quarter. The maximum permitted is four. All students receiving financial aid in the forms of fellowships, research assistantships or teaching assistantships must register as full-time students.

**Graduate Cooperative Program**

The Graduate Cooperative Engineering Education program is a program in which master's and doctor's candidates combine paid work experience in research, development, business, clinical or manufacturing positions with alternate periods of full-time academic study. The Co-op program provides opportunities for a limited number of highly qualified students to experience professional practice blended with graduate studies. The experience often permits the graduate student to gain a broader understanding of some problems that eventually could become the basis for his/her thesis or project. When appropriate opportunities exist, the work experience itself can serve as the major background for a master's project or thesis or a doctoral dissertation. For more information contact Professor Christopher Riesbeck, director of the Graduate Program, at (847) 491-7279, room 3-315 FORD, or c-riesbeck@northwestern.edu.

**General Admission Requirements**

The primary objective of the admission process in the Department is to determine an applicant's qualifications and judge the applicant's prospects for success in the desired program of study. To maintain a proper balance between Department resources and the size of the graduate student population, the process must also limit offers of admission to a small number of the most qualified applicants. Thus the admission process is highly selective and competitive in nature.

It is the policy of the EECS Department that requests for admission are reviewed during the Winter Quarter for admission the following Fall Quarter. Requests for financial aid for doctoral students are also reviewed during the Winter Quarter, with awards made for study beginning the following Fall Quarter. It is also the policy of the department that students begin their programs in the Fall Quarter. Only rarely and under special circumstances are students allowed to begin in the Winter or Spring Quarter.

Initial evaluation of each application is performed by faculty whose research interests are in the area of specialization indicated by the applicant. The faculty in the research area of the applicant evaluate the qualifications necessary for advanced study in that area. A typical applicant is expected to have a Bachelor of Science in Electrical Engineering, Computer Engineering, Computer Science, or a related discipline from a recognized institution. Highly qualified candidates with other academic backgrounds may also be considered.

The specific undergraduate preparation required for graduate study depends on the program and the area of specialization. An applicant with insufficient undergraduate preparation in some area, but well qualified in every other respect, may be required to take
certain undergraduate courses as soon as possible after enrolling at Northwestern. A student would be informed of such a requirement at the time of admission, along with grade expectations and whether such courses will carry graduate credit.

The Graduate School Bulletin, which summarizes all of the graduate programs at Northwestern, lists the materials to be submitted by all applicants for graduate study at Northwestern. In addition to this list of materials, all applicants for graduate study in Electrical Engineering and Computer Science must submit verbal, quantitative, and analytical scores from the Graduate Record Examination (GRE).

Financial Aid

Ph.D. students

The policy of the McCormick School is to admit only Ph.D. students for which financial support can be provided. The School or the department supplies support in the form of Cabell and Murphy Fellowships, research assistantships, and teaching assistantships. The department will also consider for admission students who have financial support from their institutions or governmental grants. If a student applies for aid and there is no support for him/her, the department cannot recommend to the Graduate School that the student be admitted.

M.S.-Only Students

The Department encourages M.S.-only students, especially from industry, to enroll. The department does provide financial support to M.S.-only students. Such students can be either supported by their company or be self-supported. An M.S.-only student who changes plans and wishes to pursue the Ph.D. at Northwestern after receiving the M.S. degree must reapply for admission and financial support, as discussed above.
2. M.S. Program

2.1 Course Requirements

At least 12 units of graduate study are required for the M.S. degree. Generally speaking, one unit of credit corresponds to a one quarter course. A minimum of nine courses must be taken for a grade and approved by the student's advisor. All work for the M.S. degree must be in the Northwestern University Graduate School and must be completed within a period of five years. To assure depth, every M.S. student is required to take at least three relevant courses at the 400 level (exceptions are allowed based on the recommendation of the student's advisor and the approval of the Graduate Committee), not necessarily all in EECS. 590 units (research units) do not count towards these 400 level course credits. Courses completed for undergraduate credit at Northwestern or elsewhere cannot be repeated for graduate credit.

The course 499 independent study is not intended to replace or augment required units of research 590 for either the M.S. or Ph.D. degrees. 499 will be used for projects not directly related to the thesis or project required for the degree or for readings in specific subjects for which we have no regular courses.

Graduate School policy specifies that students who have undertaken graduate study elsewhere cannot transfer credit for this work towards the master's degree here.

2.2 Thesis or Project Requirement

In addition to the course work, each student working toward an M.S. degree in Electrical Engineering and Computer Science must choose one of the following plans to be approved by the student's advisor. (These options may not be available to all Programs of Study. See Section 4 for details.)

Plan A (Thesis M.S.): The student must write an M.S. thesis for which he or she may receive two or three units of research credit 590 toward the 12 unit requirement for the M.S. degree. The thesis must be approved by the student's M.S. Examination Committee. One bound copy must be deposited in the Science and Engineering Library.

Plan B (Project M.S.): The student must complete a project and write a project report for which he or she will receive one or two units of research 590 towards the 12 unit requirement for the M.S. degree. The main difference between an M.S. thesis and an M.S. project is that a thesis normally has substantial original research results, while a project...
contains results based on existing theory or techniques. The project report must be approved by the student's M.S. Examination Committee. One copy of the project report must be placed in a spiral binder and deposited with the Department after the M.S. Final Examination.

**Plan C (Non-Thesis, Non-Project M.S.):** The student must take 12 courses, selected with the approval of the student's advisor. The choice of courses must represent a coherent program of study preparing the student for advanced work in a specific field. Students are strongly encouraged to follow the Programs of Study (POS) described in the Ph.D. program (See Section 4.). The student's performance in the coursework will be evaluated by an M.S. examination committee. Not all Programs of Study allow this option.

2.3 Residency Requirements

According to the Graduate School, the minimum residency requirement for the M.S. degree is the equivalent of three quarters of full-time registration in graduate courses. Full-time registration is defined as three or four course units per quarter. Refer to the Graduate School Bulletin for details about residency.

2.4 Resident Master's Study (588)

Registration for 588 is open to those Master's students who wish to devote themselves to full time research for one quarter. 588 allows no accumulation of credit toward residency for the degree. 588 is appropriate for students who have completed the 12-unit requirement for the M.S. degree, but have not completed the required project or thesis, and wish to maintain full-time enrollment status. Students may register for 588 in more than one quarter, but the Dean of the Graduate School will review each 588 registration beyond the first to determine that the student is making reasonable progress toward completion of the M.S. degree.

2.5 Admission to Candidacy

A grade average of B is required in all work presented in a master's degree program. The program presented must show work completed and planned which totals no less than 12 units (normally one quarter course is one unit). If more than 12 units are included on the application form it will be assumed that the additional courses are required for the degree.

A student in good standing (B average) may apply for candidacy when three units of graduate work have been completed. Students on academic probation are not eligible to apply for candidacy.

Application forms are available in the Department Office or the Graduate School and must be filed by the deadline published in the Bulletin of the Graduate School. Notification of admission to candidacy must be presented to the Department Office when making arrangements for the final examination.
2.6 Final Examination

Each student completing a Plan A or Plan B degree must pass a final examination. The examination is conducted by a committee appointed by the Associate Chair for Graduate Affairs (at the recommendation of the advisor) and composed as follows:

1. There must be at least three members who currently have faculty appointments at Northwestern University. Two of these must be members of the Department. The student's advisor normally serves as the Chairman of the Examination Committee.

2. To meet Graduate School requirements, at least two members of the Committee must be full-time faculty members of Northwestern University and at least one must be a member of the Graduate Faculty.

3. With the approval of the Associate Chair, there may be one additional voting member of the Committee from outside the University. This person should be an expert in the area of the student's research. The Associate Chair may request a resume from this outside member before the appointment.

4. Others may be invited to attend the examination as non-voting members of the Committee.

M.S. candidates who have not been Teaching Assistants or Instructors in the department are required to present their research results in the form of an open seminar. The M.S. thesis or project report should be received by all members of the Examination Committee at least one week prior to the date of the scheduled examination.

A student completing a Plan C degree must file all the same forms and paperwork and must have the final program reviewed and approved by a committee of the same kind as for Plan A or Plan B. A Plan C committee typically consists of the student’s advisor, the Associate Chair, and the Department Chairman.

2.7 Part-time Graduate Program

Graduate students may pursue their M.S. studies in the Department on a part-time basis. For this purpose the Department schedules certain courses in the late afternoon. However, all of the M.S. degree requirements must be fulfilled, and it may not be possible to take all required courses at these late-afternoon time slots. For further information, contact the Associate Chair for Graduate Affairs.
3. Ph.D. Program

The following new unit and course requirements were approved by the faculty on Feb. 17, 1999 for students entering the Ph.D. program in Fall 1999. Students who entered the Ph.D. program prior to Fall 1999 may choose to adopt these requirements as well instead of the program requirements that were in place in the 1998-99 Graduate Programs Manual.

In addition to the requirements outlined below, each program of study may have additional requirements. See Section 4 for details.

3.1 Unit Requirements

The total number of units required for a Ph.D. from the graduate school is 27. A student who receives an M.S. degree from Northwestern, or a student entering with an M.S. degree from another university in an area relevant to the Ph.D. degree pursued in our department can be granted up to 9 units of credit.

3.2. Course Requirements

Of the 27 units for the Ph.D. degree, a minimum of 15 are required to be for coursework. These 15 may include 510 units, one 545 unit, and at most two 499 units. The student must take at least 6 units of course work at the 400 or 500 levels excluding the unit for 545 and 546.

A student who is granted 9 units of credit for an M.S. degree (either from Northwestern or from another school) must take at least 6 additional units of coursework, at least 3 of which are at the 400 or 500 level excluding 545 and 546.

590 research units make up the remainder of the 27 units beyond the courses taken by the student and credit given for prior coursework.

A Ph.D. student’s research group or research advisor may require more than the minimum number of courses. In such cases the number of 590 research units will be reduced correspondingly.

The course 499 is not intended to replace or augment the required units of research (course 590) for either the M.S. or Ph.D. degrees. 499 will be used for projects not directly related to the research required for the Ph.D. thesis or for readings in specific subjects for which we have no regular courses.
3.3 Residency Requirements

A. Regular

The minimum requirement is summarized as nine quarters of full-time registration (three course units per quarter) in courses authorized by the Graduate Faculty for graduate credit. Following the first three quarters of full-time study or its equivalent, three consecutive quarters of full-time registration must be completed. Registration in the Summer Session is not required to fulfill the continuous residency requirement. Except for the three required consecutive quarters, a student may meet the residency requirement on a part-time basis as indicated in the official Graduate School Bulletin. Registration for two units in one quarter and four units in another does not equate to two full quarters of residency, but rather one and two-third quarters of residency.

B. Modification of the Continuous Residence Requirement

The consecutive three quarters of full-time residence required of doctoral students beyond the first-year level may be fulfilled by five consecutive quarters at the two-thirds load level. Such exceptions are intended for those students who can demonstrate compelling reasons such as commitments at home or the necessity of part-time employment to finance graduate study.

Employed persons who can demonstrate to the Department and the Graduate School that they have been relieved from approximately one-third of the responsibilities of full-time employment may be allowed to meet the continuous residence requirement by registering for five consecutive quarters at the two-thirds level.

Persons who wish to satisfy the continuous residence requirement as a part-time student at the two-thirds level must submit a petition to the Graduate School through the Department in advance of the period of study. A statement from the employer must be included with the petition indicating the number of hours or days each week that the part-time student will be relieved from full-time duties of employment.

C. Transfer Credit

A student with a master's degree in electrical engineering, computer engineering, computer science, or another relevant field from a recognized institution may be granted up to three quarters of transfer credit toward the nine-quarter residency requirement.

D. Special Note for Students Receiving Financial Aid

Students receiving tuition support through Northwestern University -- which includes students with teaching and research assistantships and University fellowships -- are expected to complete the 27-unit requirement in nine quarters of full-time registration.
Students receiving three quarters (9 units) of graduate credit for a master's degree are expected to complete the remaining 18 required units in six quarters. After the ninth quarter, support for only reduced-tuition courses, such as 598 and 599, will be considered by the Graduate School. Any summer quarter in which the student registers for anything other than 598 is counted as one of the nine (or six) quarters. It is therefore advisable to use only 598 or a full three units of 590 for summer registration. It is further recommended by the Dean of the Graduate School that students who have transfer credit for the M.S. degree use only 598 during the summer.

### 3.4 Requirement for Teaching Experience

The organization and presentation of knowledge and the ability to interact with others in a question-and-answer situation are integral parts of being a scientist/engineer. This is especially true for Ph.D.s who go to university positions where teaching is a major component of the work. It is also true for those who work in industry and research institutes and who have to both work with other scientists/engineers and present results in conferences and workshops. Therefore, teaching experience is an integral part of Ph.D. education, complementing coursework and research.

To that end each graduate student is required to serve as a Teaching Associate for one course of each academic year. Students who hold a teaching assistantship appointment for one or more quarters during a given academic year are exempt from participating in the Teaching Associate program that year. A Teaching Associate is expected to work 8 to 10 hours per week. It is further expected that Teaching Associates are supported either as RAs, by university fellowships, or by outside fellowships such as the NSF Graduate Fellowship.

A Teaching Associate pursing an EECS degree has to register for ECE 545 for one unit of credit during the first year; in subsequent years, the student registers for ECE 546 with no unit of credit.

Duties usually consist of grading homework problems, leading problem discussion groups, handling laboratory classes, or consulting with students. It is also recommended that during their service in the Teaching Associate program students should at least once organize and present in class a topic of an hour duration or longer. The professor in charge of the course should evaluate this presentation. It is expected that during their initial stages of their study, the Teaching Associates will be assigned to lower level classes, while more advanced students will be assigned to higher level classes related to their areas of expertise.

This teaching requirement is meant only for Ph.D. and M.S./Ph.D. student, not for terminal M.S. students.

Also, this policy will be enforced only for full-time graduate students. Part-time students will be allowed to petition out of this teaching experience requirement.
This policy becomes effective Fall 2003 (September 1, 2003) and will be retroactive to all existing graduate students as well.

3.5 Selection of a Research Topic for the Ph.D. Dissertation

Graduate students are urged to select their research topics as soon as possible after starting their graduate programs. Failure to do so often results in a delay in completing the degree requirements. Full-time Ph.D. students should identify a research advisor no later than the end of the first quarter and a research topic soon thereafter. The subject of research is of course to be selected by the students with their advisors.

The purpose of a Ph.D. dissertation is to train the student in the methods of research (that is, in how to formulate a research problem and how to proceed in a logical and systematic way to its solution). It is expected that the results be publishable in a technical journal.

3.6 Program of Study (POS) Evaluation

Each student pursuing an EECS degree must pass the program of study (POS) evaluation dictated by their respective program of study. See Section 4 for details of the POS evaluation procedures in each of the divisions in the department.

Each academic year the POST committees of the relevant divisions meet to decide which students have passed the requirements of the respective POS. The evaluation will be made on the basis of their performance in course work, research, and in some cases, and Ph.D. preliminary exam, to decide which students have passed the requirements of the POS. Students must sign up to indicate that they wish to be evaluated in a given year. Students must undergo the POS evaluation no later than their third year in the program (second year for students entering with an M.S. degree). In the event that a student does not pass the evaluation, the POS committee will make a recommendation as to whether the student should be re-evaluated at a later time or leave the program. The POS committee may also recommend that a student perform specific remedial work.

3.7 Oral Qualifying Examination

All Ph.D. students must take a division-based Qualifying Exam. This examination may cover the student’s Ph.D. dissertation research proposal as well as courses taken both in and out of the department, though emphasis is normally on the student’s area of specialization.
The student's Qualifying Examination Committee is appointed by the Dean of the Graduate School upon the recommendation of the Department Chairman and shall be composed as follows:

1. There must be at least three members who currently have full-time faculty appointments at Northwestern University. At least two committee members must be faculty members of the EECS Department. The Chair of the committee and at least one other member must be members of the Graduate Faculty of Northwestern.

2. With the approval of the Department Chairman, there may be one additional voting member of the committee from outside the University. This person should be an expert in the area of the student's research. The Department Chairman may request a resume from this outside member before the appointment.

3. Others may be invited to attend the examinations as non-voting members of the committee.

Students pursuing a CS degree typically take this examination at the end of their second year or the beginning of the third year.

Students pursuing and EECS degree typically take this examination after all course work is completed, and preliminary research results have been obtained in agreement with the student’s advisor. The examination is concerned with the student’s research proposal. The student is required to submit a written research proposal for the Ph.D. dissertation to all committee members at least one week prior to the date of the scheduled examination.

If a Ph.D. candidate changes his/her advisor and/or research topic after taking the Qualifying Examination, the student may be required to take another oral examination on the new research topic.

3.8 Admission to Candidacy

A Ph.D. student receiving financial aid is expected to be admitted to candidacy within three academic years starting from the B.S. degree or two academic years starting from the M.S. degree.

The student's application for candidacy to the Ph.D. degree is signed by the Qualifying Examination Committee after he or she passes qualifying examination. The application must be in the office of the Graduate School no later than the second week of the Winter Quarter (see Calendar for exact date) of the academic year in which the degree is to be granted. For candidates who expect to receive their degrees in December instead of June, this date may be extended to the second week of the Spring Quarter (see the University's Calendar for the exact date).
3.9 Registration After Admission to Candidacy

If the residency and course requirements have not been met when the student is admitted to candidacy, he or she is informed of those requirements that remain unfulfilled. The degree deadline date is also stipulated.

A student having been admitted to candidacy for the Ph.D. and having completed residency must register for at least three quarters of 599 Post Candidacy Research by the time the dissertation is submitted. If a student completes the degree requirements in less than three quarters after the completion of residency, he or she needs only to be registered for 599 in those quarters which intervene between the completion of residency and the submission of the dissertation. For this purpose, the Summer Session is considered a regular academic quarter.

599 registration carries full-time status without accumulation of credit. This registration does not need to be consecutive and applies whether or not a student is in residence. A person not registered loses student status.

This registration requirement does not apply to a student with a baccalaureate degree who completed all the requirements for the Ph.D. within three calendar years after initial registration or a student with the equivalent of a Master's degree who completes all the requirements for the Ph.D. within two calendar years.

Students receiving financial aid must be registered full-time. Students who do not receive financial aid and have completed the three quarters of 599 past the admission to candidacy may register for 503 if they need to use University facilities.

The Graduate School will generally not approve registration for courses after the student has been admitted to candidacy. Therefore, the student should plan to have all required courses completed before taking the oral qualifying exam.

3.10 Dissertation

Every candidate is required to present a dissertation which gives evidence of original and significant research. A copy of Instructions for the Preparation of Dissertations may be obtained from the Graduate School.
3.11 Final Examination

A candidate must pass the Ph.D. Final Examination within a period of five years from the date of the Qualifying Examination and within a period of eight years from the last year of full-time residence. The Ph.D. Final Examination is based on the candidate’s completed dissertation. The dissertation must be submitted to the members of the Examination Committee three weeks before the examination date. The examination is oral and primarily covers the dissertation and related subjects.

Students pursuing a Ph.D. in EECS who have not been Teaching Assistants or Instructors in the department are required to present their research results in the form of an open seminar. Additionally, the Qualifying Examination Committee and Final Examination Committee for students pursuing an EECS degree are normally identical. Changes of committee membership can be made with valid reason, but the same rules on the composition of the Qualifying Examination Committee are applicable to that of the Final Examination Committee.

3.12 Foreign Language Requirement

There is no Graduate School or Departmental foreign language requirement. However, the student's advisor may require knowledge of a foreign language if it is desirable.

3.13 Resident Doctoral Study (598)

Resident Doctoral Study (598) is open to doctoral students who have completed at least three full-time quarters of registration at Northwestern and who have not been admitted to candidacy. This category of registration at reduced tuition certifies full-time status, but does not allow the accumulation of credit toward residency.

598 is an appropriate full-time registration for doctoral students receiving financial aid during any quarter who do not need formal course work. 598 is also appropriate occasionally for doctoral students who need freedom from formal course work for a quarter without jeopardizing their status as full-time students during the academic year.
3.14 The Crown Family Graduate Internship Program

Ph.D. candidates may elect to participate in the Crown Family Graduate Internship Program. This opportunity permits the doctoral candidate to gain practical experience in industry or in national research laboratories in areas closely related to his or her research work. The internship can provide a significant positive impetus to the thesis effort and may provide a basis for future employment of the candidate. It is intended that the program lead to continuing collaboration between Northwestern and the participating organization.

Students elect the graduate internship option in the latter stages (e.g., third year) of the Ph.D. study. The student generally is paid by the participating sponsor and works full-time for either three, six, or nine months with that sponsor. A proper position is found with the help of the student's Ph.D. advisor and the associate deans of Graduate Studies and Research and Industry/Academic Affairs.

Students who wish to take advantage of this internship and get coursework credit need to sign up for the Graduate School General Curriculum 799-510 Crown Family Graduate Internship course for 0 units. A prerequisite for this course is a written approval of the Ph.D. advisor. Students may register for this course for no more than three quarters and no more than two consecutive quarters.

Foreign students can take advantage of this course as part of their Curricular Practical Training (CPT) without using up their quota of 12 months of Practical Training for F-1 or J-1 visas. They can register for this course during the summer quarter in which they spend their summer internship and write a report of their summer internship position for their advisor at the end of the quarter.

For details about the Crown Family Graduate Internship Program, contact the Associate Dean for Graduate Studies and Research of the McCormick School of Engineering or check out the following URL:

http://www.tgs.northwestern.edu/academics/schooloverview/mccormick/
4. Divisional Programs of Study

Every Ph.D. recipient should have a solid background in their field as preparation for a career in research or teaching. To ensure that each of our students receives this background, we require them to choose and complete the Program of Study (POS) corresponding to their intended field of inquiry. Students entering without the prerequisite knowledge to enroll in the POS courses will be required to take additional preparatory coursework. Currently the department offers six programs of study:

- Solid-State & Photonics
- Computer Engineering & Systems
- Computing, Algorithms, & Applications
- Cognitive Systems
- Signals & Systems
- Graphics & Interactive Media

Each program of study is represented by a committee of faculty who teach the courses in that program. The names of the faculty who represent various POS committees are listed below along with the detailed descriptions of each program of study.

With the consent of their advisor and the relevant POS committee, students may petition to the Graduate Committee (specifically, Prof. Christopher Reisbeck, Associate Chair for Graduate Affairs) to take alternate classes. The petition should include a brief letter of justification, the list of courses which the student intends to take to complete his/her POS and any relevant information such as a description of a similar course the student has already taken including course title, text, instructor, university, and grade received. All courses in the Ph.D. program must be selected in consultation with, and with the consent of, the student's advisor.

The three Programs of Study are described below. (Note: Not all listed courses are offered every year. The list of courses outlined below is subject to change.)

4.1. SOLID-STATE AND PHOTONICS

Faculty: Prem Kumar (Division Head), Seng-Tiong Ho, Xu Li, Hooman Mohseni, Mary Phillips, Martin Plonus, Manijeh Razeghi, Selim Shahriar, Allen Taflove, Bruce Wessels, Horace Yuen

The courses in this area are divided into Core Courses and Area Specific Courses as follows:

Core Courses (Group A)

Each student is required to take five of the following ten core courses:
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECE 382</td>
<td>Photonic Information Processing</td>
</tr>
<tr>
<td>ECE 383</td>
<td>Fiber-Optic Communication</td>
</tr>
<tr>
<td>ECE 388</td>
<td>Microelectronic Technology</td>
</tr>
<tr>
<td>ECE 401</td>
<td>Fundamentals of Electronic Devices</td>
</tr>
<tr>
<td>ECE 402</td>
<td>Advanced Electronic Devices</td>
</tr>
<tr>
<td>ECE 403</td>
<td>Quantum Semiconductors</td>
</tr>
<tr>
<td>ECE 404</td>
<td>Quantum Electronics</td>
</tr>
<tr>
<td>ECE 405</td>
<td>Advanced Photonics</td>
</tr>
<tr>
<td>ECE 406</td>
<td>Nonlinear Optics</td>
</tr>
<tr>
<td>ECE 408-1</td>
<td>Classical Electrodynamics</td>
</tr>
</tbody>
</table>

**Area Specific Courses (Group B)**

Elective courses in Solid-State and Photonics include:

- ECE 333: Introduction to Communication Networks
- ECE 381: Electronic Properties of Materials
- ECE 384: Solid-state Electronic Devices
- ECE 385: Optoelectronics
- ECE 386: Computational Electromagnetics and Photonics
- ECE 407: Quantum Optics
- ECE 408-2: Computational Electrodynamics
- ECE 409: Semiconductor Lasers
- ECE 422: Random Processes in Communications and Control I
- ECE 423: Random Processes in Communications and Control II
- ECE 424: Noise and Fluctuation in Physical/Engineering Systems
- ECE 427: Optical Communications
- ECE 428: Information Theory
- ECE 429: Selected Topics in Quantum Information Science and Technology
- ECE 454: Advanced Communications Networks
- ESAM 411: Differential Equations of Mathematical Physics

In consultation with their advisors, students can also take advanced courses (400 level) in Applied Mathematics, Physics and Astronomy, and Materials Science and Engineering, to fulfill the requirements of the Area Specific Courses.

**Course Requirements for Ph.D. Degree Students with M.S. Degree or equivalent**

A student who is granted 9 units of credit for an M.S. degree must take at least 6 units of coursework from the above lists, at least 5 of which are from the Core Courses, and 4 should be at the 400- or 500-level excluding 545 and 546.
Course Requirements for Ph.D. Degree Students without M.S. Degree or equivalent

A minimum of 15 of the 27 required units must be courses. These 15 may include 510 units, one 545 unit, and at most two 499 units. The student must take at least 8 units of coursework at the 400- or 500-level excluding 545 and 546.

Ph.D. Program of Study Evaluation

The Solid-State and Photonics POS evaluation will be made by the Solid-State and Photonics POS Committee on the basis of the following criteria: (1) the student’s performance in coursework, (2) the student’s performance in research, and (3) an oral exam. The oral examination requirement can be bypassed if so deemed by the student’s advisor. The oral examination is conducted by a committee selected by the POS committee and consisting of at least three faculty members with expertise in the examination area. Some of the committee members can be faculty members from outside the EECS Department. The exam is offered once a year and students must sign up for the exam with Professor Allen Taflove, the Graduate Director. Students will be given two attempts to pass the POS Evaluation. However, each student must take the Evaluation by the end of the student’s second year in order to continue in the Ph.D. program.

4.2. COMPUTER ENGINEERING & SYSTEMS

Faculty: Alok Choudhary (Division Head), Randy Berry, Fabian Bustamante, Yan Chen, Brian Dennis, Robert Dick, Peter Dinda, Larry Henschen, Yehea Ismail, Russ Joseph, Aleksandar Kuzmanovic, Wei-Chung Lin, Gokhan Memik, Seda Memik, Alan Sahakian, Peter Scheuermann, Chi-Haur Wu, Hai Zhou

Core Courses

Each student must take the following two core courses:

ECE 361: Computer Architecture
CS 336: Design and Analysis of Algorithms

Area-Specific Courses

In addition, each student must choose three of the following six tracks and take at least two courses from each chosen track. ECE 361 and CS 336 can help fulfill the track requirement. A course that is listed in two different tracks can fulfill both track requirements. Students are tested on the material contained in the highlighted courses in the Program of Study Exam. In the case of Digital Design and VLSI, students may choose to be tested on either ECE 357 or ECE 391.
A. Digital Design & VLSI

ECE 303: Advanced Digital Logic Design
**ECE 357:** Introduction to VLSI CAD
**ECE 391:** VLSI Systems Design
ECE 346: Microprocessor System Design
ECE 459: VLSI Algorithmics
ECE 397: High Performance Issues in VLSI Circuits
ECE 510-20: Issues in High-Performance Integrated Circuits

B. Architecture

ECE 361: Computer Architecture
**ECE 452:** Advanced Computer Architecture
ECE 453: Advanced Computer Architecture II

C. Software and Data Engineering

CS 351: Introduction to Computer Graphics
CS 322-1: Compiler Construction I
CS 339: Introduction to Database Systems
**CS 343:** Operating Systems
ECE 455: Distributed Computing Systems
ECE 467: Parallel and Distributed Database Systems

Other 300- and 400- level courses from the CS department in the software area can fulfill software track requirements (with the consent of the advisor).

D. Parallel and Distributed Computing

**ECE 358:** Introduction to Parallel Computing
ECE 455: Distributed Computing Systems
ECE 333: Introduction to Communication Networks
ECE 467: Parallel and Distributed Database Systems
ECE 453: Advanced Computer Architecture II

E. Numerical Computing

**ECE 328:** Numerical Methods for Engineers
ECE 479-1,2: Nonlinear Optimization
ESAM 446-1,2,3: Numerical Solution of Partial Differential Equations

F. Algorithms

**ECE 459:** VLSI Algorithmics
ECE 457: Advanced Algorithms
IEMS 452: Combinatorial Optimization
The Computer Engineering Ph.D. program of study evaluation involves a written exam. The written exam will take place on the second Saturday in October. Students must sign up for the exam during the first week of the Fall Quarter with Professor Chris Riesbeck, the Associate Chair for Graduate Affairs. Students will be tested based on the materials in the two core courses (ECE 361 and CS 336) and based on the highlighted courses in their choice of one of the six tracks listed above. Both the POS written exam and the POS evaluation are in the Fall quarter.

The Computer Engineering POS evaluation will be made by the Computer Engineering POS Committee on the basis of a student’s performance in coursework, research, and the Computer Engineering Ph.D. POS written exam. Students will be allowed two attempts to pass the Evaluation. However, each student must pass the Evaluation by the beginning of the student’s third year to continue in the Ph.D. program.

4.3. COMPUTING, ALGORITHMS, & APPLICATIONS

Faculty: Ming Kao (Division Head), Yan Chen, Jorge Nocedal, Peter Scheuermann, Allen Taflove, Hai Zhou

Research Scope and Opportunities in the Division:
The research of this division focuses on algorithms, theory, applications, and software and hardware implementations.

Current research areas include bioinformatics, computational economics and finance, continuous and discrete optimization, database algorithms, formal methods, networking algorithms, security algorithms, self-assembly, and VLSI CAD algorithms.

Overall Schedule and Model of the Ph.D. Study Process:
You are strongly expected to finish your Ph.D. study in 4 years. Generally, you should make every effort to follow the following schedule:

1. find a faculty member to be your Ph.D. advisor no later than the end of the spring quarter of your 1st year, but preferably by the end of the fall quarter of the 1st year;
2. take courses during the first two years;
3. pass the qualifying exam by the end of the 2nd year;
4. pass the Ph.D. thesis proposal defense by the fall quarter of the 3rd year;
5. complete the writing of your Ph.D. thesis by the end of the winter quarter of the 4th year; and
6. defend your Ph.D. thesis during the spring of the 4th year.
Prior to joining the EECS Department, you are strongly encouraged to visit Northwestern to get a first-hand sense of the research opportunities here. It is essential that you identify at least one faculty member with whom you would like to conduct research.

Your choice of an advisor is of critical importance. Your advisor will guide you, help you, fund you, and promote you. We believe in the apprenticeship model of Ph.D. education. How you learn to do research and your style and taste in problems will be formed in large measure by your advisor.

In choosing an advisor, you should take the initiative to discuss with any faculty member who interests you upon your joining Northwestern or even before then. Generally, you should find an advisor by the end of the fall quarter (your 1st quarter). The remainder of this document assumes you have chosen a faculty member in the CAA Division as your advisor.

Preferably by the beginning of your 2nd quarter, you should proactively engage in research. In your first year or two, you will also be taking classes, but doing research will determine your success as a graduate student. Throughout your graduate student years, two thirds of your time should be spent on research. The objective of Ph.D. study is to become a good independent researcher. Except in extremely rare cases, the most effective way to learn how to do research is to do research under the guidance of your advisor and other faculty members. You also want to determine very quickly whether research is for you. Remember, you are not in graduate school to take classes.

By the end of your 2nd year, you will take the CAA Division qualifying exam, which is described in detail below. The next step after the qualifying exam is to find a Ph.D. thesis topic. This can take some time and it is easy to get lost during the process. This makes it all the more important to work with your advisor. Once you have a good topic, you will embark on the Ph.D. thesis process as described below.

**Importance of Self-Motivation and Self-Initiative:**
A Ph.D. student is expected to be strongly self-motivated. Unlike undergraduate study or a master’s program, Ph.D. level study involves long periods where the primary driver is the student himself. The search for the Ph.D. thesis topic is the most critical of these periods.

A Ph.D. student is also expected to increasingly take the initiative in research as he or she progresses in the program. By the time the student formulates the Ph.D. thesis proposal, and ideally well before, the student should feel comfortable suggesting research directions, disagreeing with literature, and taking on side projects.

**Understanding Funding:**
Students in the Northwestern EECS Department are funded during the academic year through university fellowships, external fellowships, teaching assistantships (TAships) and research assistantships (RAships). Funding depends on adequate progress toward the Ph.D. and available funding sources. It is not guaranteed.
• Some University fellowships, e.g., Murphy and Cabell, typically apply only to first-year students. These funds are generally provided, in a department-level competition, on the basis of the perceived quality of the incoming students and the policies of the Graduate School. After the Ph.D. thesis proposal, the Dissertation Year Fellowship and other fellowships may apply.

• External fellowships, e.g., the NSF, NASA, and DOD Graduate Fellowships, are awarded directly to students, provide the maximum flexibility to the awardees, and invaluably enhance the awardees’ own career credentials. We strongly expect that students will take the initiative in seeking external funding.

• TAships can fund students at any stage in the Ph.D. study. TAships are distributed according to a department-level competition and generally require that the student to teach. All students, regardless of funding, may be expected to be a teaching assistant one quarter per year. Being funded on a TAship may mean that you have to teach more. The time involved in being a teaching assistant for a course should not exceed 20 hours a week on average. If you find that you are spending more than 15 hours per week on average being a teaching assistant for a course, you should immediately inform your advisor.

• RAships are funding that is provided as part of a research grant, generally your advisor's grant, and generally a grant from the federal government. If you are funded from an RAship, the expectation is that you will do, in part, research and development related to the grant, as determined by your advisor. This is generally a very workable situation as you hopefully share at least some of your advisor's interests and those interests are partially reflected in the grant and its work. Most advisors are extremely happy when students take the initiative in suggesting work to be done while funded on an RAship. New faculty members generally have some degree of student support as a part of their startup packages. From the point of view of students, these funds act just like RAships.

There are no fellowships (other than perhaps external fellowships) or TAships during the summer months. Summer funding derives almost entirely from RAship funding and is not guaranteed. The expectation is that students funded during the summer will work full time on the research of the underlying grant.

Students are encouraged to seek out summer funding of their own in the form of internships at quality research laboratories. Students who are interested in doing a summer internship must take the initiative in finding appropriate opportunities. Generally, this should be done in December.

**Acquiring Breadth in Computer Science:**
Good researchers understand the big picture of not only their own research areas but also related fields. Before taking the CAA qualifying exam, you should have taken at least three courses in the following three areas in Computer Science with
• at least one from Computer Engineering and Systems, and
• at least one from Cognitive Systems or Graphics and Interactive Media.
We list here courses from the EECS Department. With the consent of your advisor, you may substitute other courses. You may also be able to “test out” of areas; see the course coordinator if you are interested. You must submit a computer science breadth requirements form to the graduate coordinator to document your fulfillment of these requirements.

- Graphics and Interactive Media: CS330, CS351.

**Acquiring Breadth in Computing, Algorithms, and Applications:**

A CAA researcher in some specific area should be familiar with work in other areas of computing. The expectation for CAA students is that they have deeper knowledge of computing in general than of Computer Science or EECS as a whole. Each area below is listed with appropriate corresponding Northwestern introductory and advanced courses. These courses have online syllabi, and some have online reading lists. You should familiarize yourself with the contents of those syllabi and reading lists. You need not have taken these specific courses, but you should be familiar with their key concepts. Also, with the consent of your advisor, you may substitute other courses.

You must take at least 6 courses in the following areas. You also must take at least one course in each of Computational Complexity, and Continuous Optimization, and Discrete Algorithms. You may be able to “test out” of areas; see the course coordinator if you are interested. You must submit the CAA breadth requirements form to the graduate coordinator to document your fulfillment of these requirements.

- Computational Complexity
- Continuous Optimization:
  - ECE479 Nonlinear Optimization
- Discrete Algorithms:
  - CS336 Design and Analysis of Algorithms
  - ECE457 Advanced Algorithms
- Databases:
  - CS339 Introduction to Database Systems
  - ECE467 Parallel and Distributed Database Systems
- Networking and Security:
  - CS340 Introduction to Computer Networking
  - CS440 Advanced Computer Networking
  - CS350 Introduction to Computer Security
  - CS450 Internet Security
- Scientific Computing:
  - ECE328 Numerical Methods
  - ESAM446 Partial Differential Equations (Parts 1 and 2)
- VLSI CAD:
  - ECE357 Introduction to VLSI CAD
  - ECE459 VLSI Algorithmics
  - ECE397 Formal Techniques in Design and Verification
- Mathematics, Probability, and Statistics:
  - IEMS303 and 304 Statistics 1 and 2
Acquiring Depth in Computing, Algorithms, and Applications:
How to acquire depth in your research area will be determined by your advisor. Generally, it takes the form of taking additional graduate courses and doing guided research and reading. By the end of your 2nd year, we expect that you will have made research contributions.

Qualifying Exam:
The purpose of the CAA Division Qualifying Exam is to determine whether you have the essential prerequisites of being a doctoral-level researcher, namely:

- Have you acquired a breadth of knowledge in computer science and computing, algorithms, and applications?
- Do you have a depth of knowledge in your research area?
- Can you do research?
- Can you present your research well, both in written form and orally?
- Can you defend and promote your research?
- Can you think and discuss research extemporaneously? In other words, can you think on your feet?

If you do not meet these prerequisites, you will not pass the exam. In some cases, such as if you fail due to insufficient breadth or depth, you may be able to retake the exam. The exam can be retaken only once.

You should ask your advisor if you are ready to take the CAA Division Qualifying Exam. If your advisor agrees, you should form a Qualifying Exam Committee consisting of your advisor and at least two other CAA faculty members. Non-CAA committee members from outside the CAA Division, the EECS Department, or the University are also appropriate in some situations with consent by your advisor. It is your responsibility to schedule the exam and reserve a conference room for it. Exams will typically take two hours. Exams are private: only your committee and you are in the room.

The exam will begin with your presentation of a significant piece of research that you have done. Fourteen days before the exam, you must supply the committee with a paper about the work. A workshop, conference, or journal paper is ideal. The committee will ask you tough questions about the content of the presentation and the work. The purpose of this part of the exam is to determine whether you are capable of doing research, presenting it, defending it, and promoting it well.

In the next stage of the exam, each of your committee members will have the opportunity to ask you questions. Any technical question related to computer science is fair; however the focus will be on CAA areas. Many faculty members prefer to start with a question designed to test your breadth or depth of knowledge in computer science. The committee may follow up on such questions, probing to find out what you know and what you do not know. The committee is particularly interested in how you respond to questions in areas you do not know or that you do not know the answer to. This is a common situation in doing research and the committee wants to know how you respond to it. It is appropriate and encouraged to ask questions of the
committee. The committee also wants to see how you respond in an intellectual
dialog.

After the exam, the committee will deliberate and write you a formal letter. Four
outcomes are possible:

- Pass. You have done great.
- Conditional Pass. You did OK. The letter will explain what you need to do to
  improve and the process by which you and your advisor will make it happen.
- Fail with Possibility of Retake. You failed, but the committee thinks there is
  hope for you. The letter will outline what you need to do before you retake
  the exam.
- Fail without Possibility of Retake. You failed and the committee does not
  believe you will ever pass.

All members of the committee will receive a copy of the letter.

If a student changes his/her advisor after passing the qualifying exam, the new
advisor may require the student to take another qualifying exam. Similarly, if a
student changes his/her research topic after passing the qualifying exam, the advisor
may require the student to take another qualifying exam on the new topic.

**Thesis Research Process:**
The objective of the Ph.D. thesis research process is to demonstrate that you can
independently formulate a significant new research question, conduct the research
necessary to answer it, and compellingly defend, promote, and publish your results.
Successfully completing the Ph.D. thesis earns you a Ph.D. degree and hence
establishes you as a person who has accomplished the above objective.

The Ph.D. research thesis process generally takes from one to two years to
complete.

**Thesis Committee:**
The Ph.D. thesis is judged by a committee that is chosen by the student and the
student’s advisor. This Ph.D. Thesis Committee commits to reading and commenting
guidance and advice as the Ph.D. thesis work progresses, reading and commenting

The Committee is chaired by the student’s advisor and must consist of at least three
internal members from the tenured or tenure-track faculty of the EECS Department
and at least one external member from outside the EECS Department or the
University. The internal committee members are usually, but not always, drawn from
the CAA Division.

It is the responsibility of the student to form the committee and to schedule it for the
proposal and thesis defenses.
**Thesis Proposal:**
The Ph.D. thesis proposal is a document written by the student that describes the proposed Ph.D. thesis. It must contain:

- **Thesis statement.** What is the specific research problem being addressed and what is the proposed solution?
- **Related work.** What have other people done in this area and why is the proposed solution new?
- **Prior work.** What work has the student done already that suggests that she or he is capable of addressing the problem?
- **Expected contributions.** What artifacts and results are expected?
- **Work plan and schedule.** What major tasks does the student plan to do? When will they be completed? Of course, research often takes one in unplanned directions. The point of the work plan and schedule is to describe what path is currently expected. Also, notice that writing the thesis itself is the most important task of Ph.D. study, is highly time-intensive and energy-intensive, and should be explicitly discussed in the work plan and schedule.

A Ph.D. thesis proposal is generally 10-15 pages long and prepared in consultation with the advisor. The proposal must be given to the Ph.D. Thesis Committee and posted in written form in a public place in the Department at least 14 days before the proposal defense. It is not necessary to make the proposal available online.

**Thesis Proposal Defense:**
The proposal defense is an open public talk, given in front of the Ph.D. Thesis Committee and any members of the EECS Department who care to attend. The open segment of the proposal defense is followed by a closed segment attended only by the Committee and the student.

The student must schedule the defense, making sure all her or his committee members are present physically or via phone conference. The student must assure that the proposal defense is advertised to the EECS department at least 14 days before it occurs. It will specifically be posted as a Ph.D. thesis proposal talk.

The talk is a summary of the Ph.D. thesis proposal and a defense of its ideas. It’s the final sanity check before the Ph.D. thesis work begins and is very important.

Generally, a Ph.D. thesis proposal talk lasts about 50 minutes, although there is no set time. Only clarification questions are permitted during the talk. After the talk, each member of the Committee, in an order determined by the committee chair, will ask in-depth questions. Once the Committee is finished with public questions, further questions will be solicited from the audience.

After public questions have been exhausted, the audience will leave and the committee may ask further private questions, or raise other private concerns.

The student will then leave the room and the Committee will determine whether the student has passed or failed the proposal defense. The student will be informed whether she or he has passed or failed on the day of the proposal defense. In either case...
case, the Chair of the Committee will write a formal letter to the student describing the results and what additional work, if any, is to be done. All members of the committee will be given a copy of the letter.

**All but Thesis:**
After a successful proposal defense, the student will carry out the work described in the proposal, modifying her or his research plan in consultation with the committee, and, most importantly, the student’s advisor.

**Ph.D. Thesis:**
A Ph.D. thesis is a book describing the work carried out during the Ph.D. thesis process and its questions and results. It must be well written and be sufficiently self-contained.

The Ph.D. thesis document must be complete, in draft form, before the Ph.D. thesis defense can take place. It must be provided to the members of the committee at least 30 days before the defense is to take place.

A summary of the Ph.D. thesis (generally 10-15 pages) must be posted in a public place in the Department at least 14 days before the defense is to take place.

**Thesis Defense:**
The procedures for the Ph.D. thesis defense are similar to those of the proposal defense. The defense is an open public talk, given in front of the Committee and any members of the EECS Department who care to attend. The open segment of the defense is followed by a closed segment with only the Committee and the student.

The student must schedule the defense, making sure all her or his committee members are present physically or via phone conference. The student must assure that the defense is advertised to the EECS department at least 14 day before it occurs. It will specifically be posted as a Ph.D. thesis defense talk.

The talk is a summary of the Ph.D. thesis work and a defense of its ideas and results.

Generally, a defense talk lasts about 50 minutes, although there is no set time. Only clarification questions are permitted during the talk. After the talk, each member of the committee, in an order determined by the Committee Chair, will ask in-depth questions. Once the Committee is finished with public questions, further questions will be solicited from the audience.

After public questions have been exhausted, the audience will leave and the committee may ask further private questions, or raise other private concerns.

The student will then leave the room and the Committee will determine whether the student as passed or failed the Ph.D. thesis defense. In either case, the Chair of the Committee will write a formal letter to the student describing the results and what additional work, if any, is to be done. All committee members will be given a copy of the letter.
Final Step of the Ph.D. Study Process:
After a successful thesis defense, your committee will, within 14 days, send comments on the thesis draft to you. You will then complete any additional work and make the necessary changes to the thesis. You must deliver the finalized thesis by both submitting it to the University Library and publishing it as a departmental technical report. After you have delivered your thesis, congratulations to you and your advisor!

4.4. COGNITIVE SYSTEMS
Faculty: Ken Forbus (Division Head), Larry Birnbaum, Justine Cassell, Peter Dinda, Daniel Edelson, Louis Gomez, Kristian Hammond, Larry Henschen, Ian Horswill, Don Norman, Andrew Ortony, Bryan Pardo, Christopher Riesbeck, Uri Wilensky

Students in this category are interested in
- Understanding how minds work, from a computational perspective.
- Creating systems for helping people learn better and perform better, using principles of Cognitive Science.
- Using Artificial Intelligence techniques to create new forms of interactive entertainment.

Courses serve two purposes. The first is to fill any gaps in your Computer Science background, if necessary. (If your undergraduate major was something other than Computer Science, or had significant gaps, C-level courses provide a means of catching up.) The other purpose of courses is to help you explore new areas. Your course work will vary depending on your exact interests and your background. Someone deeply interested in Cognitive Science might take a number of courses in Psychology. Someone interested in creating new kinds of educational software might take some of their courses in the School of Education and Social Policy. Someone interested in more applied AI might take some of their courses in human-computer interaction and interface design.

By the time of the qualifying exam, you should be conversant with the material in the following courses:

- CS 325: Artificial Intelligence Programming
- CS 337: Introduction to Semantic Information Processing
- CS 338: Practicum in Intelligent Information Systems
- CS 344: Design of Computer Problem Solvers
- CS 348: Introduction to Artificial Intelligence
- CS 395: Situated Information Retrieval
- CS 395: Knowledge Representation

If you believe that you have had equivalent courses before, that is fine, but please check the specifics of the syllabi and talk to your advisor. Don’t just rely on the course titles.

It is crucial to realize that, unlike undergraduate study, graduate school is primarily about research, not courses. We expect you to do well in your courses, naturally. However, we
expect you to become involved in research starting in your first year. Independent study projects are a good way to explore what kind of work you want to become involved in, or just to wrap your head around something different if you are already involved in a project. Instead of a Master’s thesis, we encourage students to publish research in conferences and journals, starting early in their career.

4.5. SIGNALS & SYSTEMS

Faculty: Alan Sahakian (Division Head), Randy Berry, Arthur Butz, Robert Dick, Randy Freeman, Dongning Guo, Abraham Haddad, Michael Honig, Yehea Ismail, Aggelos Katsaggelos, CC Lee, Wei-Chung Lin, Thrasos Pappas, Jack Tumblin, Chi-Haur Wu, Ying Wu, Horace Yuen

Core Courses

All students must take the following four core courses:

ECE 307: Communications Systems
ECE 359: Digital Signal Processing
ECE 410: System Theory
ECE 422: Random Processes in Communication and Control I

Elective Courses

Each student must select three from the following list of seven courses:

ECE 332: Digital Image Analysis
ECE 333: Introduction to Communication Networks
ECE 360: Introduction to Feedback Systems
ECE 378: Digital Communications
ECE 420: Digital Image Processing
BME 383: Cardiovascular Instrumentation
BME 402: Advanced Systems Physiology

Area Specific Courses

In addition, each student must complete a sequence of courses in an area of specialization according to the recommendation of the advisor. These courses may be in the Systems and other areas. Elective courses in Systems may include:

ECE 363: Digital Filtering
ECE 374: Introduction to Digital Control
ECE 380: Wireless Communication
ECE 418: Advanced Digital Signal Processing
ECE 420: Digital Image Processing
ECE 421: Multimedia Signal Processing
ECE 423: Random Processes in Communications and Control II
ECE 426: Signal Detection and Estimation
ECE 427: Optical Communications
ECE 428: Information Theory
ECE 432: Advanced Computer Vision
ECE 435: Neural Networks
ECE 454: Advanced Communication Networks
ECE 478: Advanced Digital Communications
ECE 485: Local Area Networks
BME 384: Biomedical Computing
BME 402: Systems Physiology

**Ph.D. Program of Study Evaluation**

The Systems Ph.D. program of study evaluation involves a written exam which consists of two parts. The first part of the exam covers Communication Systems (ECE 222 and ECE 307), Signal Processing (ECE 359), Linear Systems (ECE 410), and Probability and Random Processes (Math 330 and ECE 422). All students are responsible for all materials in the first part of the exam. The second part of the exam covers Communication Networks (ECE 333), Control (ECE 360), Digital Communications (ECE 378), Image Processing (ECE 420), and Instrumentation (BME 383). Each student is responsible for three of the five areas in the second part of the exam.

The Systems POS evaluation will be made by the Systems POS Committee on the basis of a student’s performance in coursework, research, and the Systems POS written exam. The exam and corresponding evaluation are offered twice per year, towards the end of the Fall and Spring quarters. Students must sign up for the exam with Professor Allen Taflove, the Graduate Director. Students can choose between the Fall and Spring exams and they will be given two attempts to pass the evaluation. However, each student must pass the Evaluation by the end of the student’s second year to continue in the Ph.D. program.

**4.6. GRAPHICS & INTERACTIVE MEDIA**

**Faculty:** Ian Horswill (Division Head), Larry Birnbaum, Justine Cassell, Brian Dennis, Peter Dinda, Daniel Edelson, Louis Gomez, Bruce Gooch, Kristian Hammond, Don Norman, Andrew Ortony, Bryan Pardo, Jack Tumblin, Ben Watson, Uri Wilensky

Students should have the knowledge described in the basic core computer graphics series: CS 351-353. Additional courses may be needed specific to your area of graphics. These will be determined in agreement with your advisor.

Students in this area also need a fairly broad understanding of computer science, with knowledge of both systems and mathematical aspects of the field. This is not to say that you should take all or even any of these courses, and no specific courses are officially required for your degree. However, the material from the following courses may be required to pass the quals:
CS 213 Introduction to Computer Systems  
CS 310 Mathematical Foundations of CS  
CS 325 Artificial Intelligence Programming  
CS 330 Human Computer Interaction  
CS 336 Design and Analysis of Algorithms  
CS 339 Introduction to Databases  
CS 340 Networking  
CS 343 Operating Systems  
CS 345 Distributed Systems  
CS 348 Intro to AI  

Students are also encouraged to branch out and learn other areas, and may be required to by their advisor. These areas may include: Perception (Psych), Cognitive Science (Psych, Ling), Classical robotics (ECE, MechE), Motion dynamics (Eng), Advanced Mathematics, Control theory (ECE, MechE), Signal Processing (ECE, CS), Electronics, Computer Architecture (ECE), Mechanical design, Art and Performance, Design (IIT’s Inst. Design), Computer Music, and Statistics.

A sample course plan for graphics students will vary slightly depending on the exact course of study. Talk with your advisor. The courses listed above should be taken as soon as possible, especially if your undergraduate background was lacking in one of these areas. One possible schedule is shown below, with possible Core Area classes to be filled in accordingly.

Fall Yr 1: CS 351; research with advisor (CS 499); one of CS courses above.  
Wtr Yr 1: CS 352; CS 499; one of CS courses above.  
Spr Yr 1: CS 353; CS 499; one of non-CS courses above.  
Fall Yr 2: Special topic in graphics (CS 495); CS 499; one of CS courses above.  
Wtr Yr 2: Two credits CS 499; one of non-CS courses above.  
Spr Yr 2: Stop taking courses! Do your research and study for the qualifying exam!
5. Department Research Areas

Specific topics of research for individual faculty are listed in Section 8. There are several focused research areas as well; these represent major research thrusts that involve several faculty and for which the department is especially noted. These research thrusts are described within the three program groups discussed in Section 4. The contact person’s name is highlighted.

1) Solid State and Photonics – Professors Prem Kumar (Division Head), Seng-Tiong Ho, Xu Li, Hooman Mohseni, Mary Phillips, Martin Plonus, Manijeh Razeghi, Selim Shahriar, Allen Taflove, Bruce Wessels, Horace Yuen

This combines two thrust areas:
Solid State Engineering focuses primarily on the science and technology of semiconductors for quantum structures and devices operating from the ultraviolet up to far infrared. Quantum devices are fabricated using the most advanced semiconductor synthesis technologies (MOCVD, MBE, gas source MBE...), as well as micro-fabrication techniques (high-precision photolithography, e-beam evaporation, RTA, reactive-ion-etching...). The quantum devices are fully tested at each step in the fabrication process using advanced characterization techniques (diffraction, SEM, TEM, photoluminescence, Hall...). Most of the research is performed within the Center for Quantum Devices, in a 'clean room' environment similar to what is found in industry. These quantum devices are highly demanded by today's applications. Ultraviolet lasers and photodetectors are needed for astronomy, space communications and the monitoring of engines and heat sources. Red, green and blue (RGB) solid-state lasers are needed for high brightness full-color displays and optical data storage (CD, DVD). High power 0.808 µm, 0.98 µm, 1.3 µm and 1.5 µm lasers and VCSELs are needed for medical applications and fiber optical communications. Infrared lasers (e.g. Quantum Cascade lasers), photodetectors (e.g. QWIP) and focal-plane-arrays (FPA) are needed for chemical analysis and night vision.

Study in the area of optical systems and technology focuses on micro-cavity lasers, nano-structures, quantum and nonlinear optics, integrated optics, fiber-optic and infrared waveguide devices, fiber-optic communications, computational electromagnetics, and imaging through turbulence. Special emphases include: applications of novel quantum amplifiers in optical communications, imaging, and cryptography; devices for tera-bit per second WDM and TDM optical networks; and applications of computational techniques in integrated and nonlinear optics.
2) **Computer Engineering & Systems** - Professors Alok Choudhary (Division Head), Randy Berry, Fabian Bustamante, Yan Chen, Brian Dennis, Robert Dick, Peter Dinda, Larry Henschen, Yehea Ismail, Russ Joseph, Aleksandar Kuzmanovic, Wei-Chung Lin, Gokhan Memik, Seda Memik, Alan Sahakian, Peter Scheuermann, Chi-Haur Wu, Hai Zhou

Areas of study in the Computer Engineering and Systems Division fall into seven main categories: analysis and design of integrated circuits, computer architecture, high-performance and parallel computing, embedded systems, data management and analysis, security, as well as distributed systems and networks. Example subtopics within each category follow.

Analysis and design of integrated circuits: design verification; integrated circuit synthesis; model order reduction; and physical design of integrated circuits.

Computer architecture: application-specific programmable processors; power-aware microarchitectures; reconfigurable architectures; and reliable high-performance processor design.

High-performance and parallel computing: compilers and applications; high-performance storage and parallel I/O; and ultra-scale architectures and software.

Embedded systems: embedded system synthesis; mobile, wireless, and ubiquitous computing; operating systems; power optimization.

Data management and analysis: data mining and knowledge discovery; moving objects databases; parallel and distributed database systems; and physical database design.

Security: network security; secure architectures; and secure software.

Distributed systems and networks: autonomic computing; network measurement and performance analysis; network protocols and security; peer-to-peer and overlay networks; resource virtualization; ubiquitous computing and journalism; as well as wireless, ad-hoc, and sensor networks.

3) **Computing, Algorithms, & Applications** – Professors Ming Kao (Division Head), Yan Chen, Jorge Nocedal, Peter Scheuermann, Allen Taflove, Hai Zhou

*Please see Division Head for detailed Research information.*
4) **Cognitive Systems** – Professors Ken Forbus (Division Head), Larry Birnbaum, Justine Cassell, Peter Dinda, Daniel Edelson, Louis Gomez, Kristian Hammond, Larry Henschen, Ian Horswill, Don Norman, Andrew Ortony, Bryan Pardo, Christopher Riesbeck, Uri Wilensky

*Please see Division Head for detailed Research information.*

5) **Signals & Systems** – Professors Alan Sahakian (Division Head), Randy Berry, Arthur Butz, Robert Dick, Randy Freeman, Dongning Guo, Abraham Haddad, Michael Honig, Yehea Ismail, Aggelos Katsaggelos, CC Lee, Wei-Chung Lin, Thrasos Pappas, Jack Tumblin, Chi-Haur Wu, Ying Wu, Horace Yuen

Study in the area of Networks, Communication and Control focuses on communications, telecommunications and communication networks, and control theory. Specific areas of study include: mobile wireless multi-user communication, estimation and detection, wireless networks, resource allocation in communication networks, data network protocol design, network performance modeling and analysis, nonlinear and robust control, and stochastic hybrid systems.

Study in the area of Signal Processing focuses on the digital representation and algorithmic manipulation of speech, audio, image and video signals. Specific topics within this general area include image and video processing, recovery and compression, multimedia signal processing, filter design and rank-order operators, image and video transmission, medical and biomedical signal processing, medical imaging, and algorithms for medical instrumentation.

6) **Graphics & Interactive Media** – Professors Ian Horswill (Division Head), Larry Birnbaum, Justine Cassell, Brian Dennis, Peter Dinda, Daniel Edelson, Louis Gomez, Bruce Gooch, Kristian Hammond, Don Norman, Andrew Ortony, Bryan Pardo, Jack Tumblin, Ben Watson, Uri Wilensky

*Please see Division Head for detailed Research information.*

Many EECS faculty are involved in research in various interdisciplinary research centers.

- Optimization Technology Center (J. Nocedal, Co-Director)
- Center for Quantum Devices (M. Razeghi, Director)
- Center for Dynamic Systems and Control (A. Haddad, R. Freeman, Directors)
- Motorola Center for Telecommunications Research (A. Katsaggelos, Director)
- Center for Photonic Communication and Computing (P. Kumar, Director)

Other areas of research pursued by EECS faculty are listed in the description of faculty in Section 10.
NEW STUDENT SIGN-UP LIST

New graduate students should circle up to two sub-areas and place numbers 1 and 2 next to the circles to indicate priority of research area. For example, a student could circle sub-area 1.1 and sub-area 1.3 as his/her top two choices.

AREA 1: Solid State and Photonics

1.1 Solid state
1.2 Quantum optics
1.3 Electrodynamics
1.4 Photonic communication

AREA 2: Computer Engineering & Systems

2.1 Parallel and distributed computing
2.2 Computer architecture
2.3 VLSI and CAD design and theory
2.4 Distributed database systems and data mining

AREA 3: Computing, Algorithms, & Applications

Please see Division Head for sub-area information.

AREA 4: Cognitive Systems

Please see Division Head for sub-area information.

AREA 5: Signals & Systems

5.1 Networking
5.2 Wireless communication
5.3 Image, signal, and multimedia processing
5.4 Control

AREA 6: Graphics & Interactive Media

Please see Division Head for sub-area information.

NAME______________________________

DATE_______________________________     SIGNATURE_____________________________
6. Student Related Activities and Organizations

Institute of Electrical and Electronics Engineers - Student Chapter (IEEE)

Faculty Counselor: Professor A. V. Sahakian

The Institute of Electrical and Electronics Engineers (IEEE) is the principal professional society in the electrical engineering profession. It has over 300,000 members, including 38,000 student members. It publishes more than 40 technical journals and sponsors or co-sponsors more than 1,000 scientific conferences and meetings around the world covering all aspects of electrical engineering and related fields. It has a student branch in every major university in the free world that offers an electrical engineering curriculum. The student Branch at Northwestern University is well established and sponsors a number of technical meetings every year. The Department provides an office for the Student Branch. Student members are entitled to receive the monthly publication, Spectrum; subscribe to the special publications of the IEEE technical societies (there are 35); and attend any of the IEEE-sponsored or co-sponsored conferences at substantially reduced rates. Students are encouraged to join the organization. Application forms can be obtained at the Student Branch office, the Department Office, or from Professor Sahakian. (Current basic dues are $30/year.)

Optical Society of America – Student Chapter (OSA)

Faculty Advisor: Professor Prem Kumar

The Optical Society of America was founded in 1916 with the mission to increase and diffuse the knowledge of optics and to promote the common interests of and encourage cooperation among scientists, designers, and users of optical apparatus of all kinds. Today there are over 12,500 members worldwide representing 50 countries. Through its sponsorship of conferences, peer-reviewed journals and a monthly optics and photonics news magazine, OSA has emerged as one of the leading and most prestigious organizations serving the optics and photonics community. Northwestern is very active in the OSA with four professors (Ho, Kumar, Razeghi, and Wessels) who are Fellows of the society. The Student Chapter hosts regular meetings with invited speakers, participates in community outreach activities, and sponsors social gatherings for its members. Students are encouraged to join the Student Chapter to become involved with the exciting research activities of the optics and photonics community at Northwestern University.
Beta Tau Chapter of Eta Kappa Nu
Faculty Advisors: Professors A. Taflove and A. V. Sahakian

Eta Kappa Nu is the national electrical engineering honor society. It was founded in 1904 at the University of Illinois and now includes more than one-hundred collegiate and alumnus chapters. Our chapter at Northwestern, Beta Tau, was installed on January 24, 1948.
Membership is by invitation to electrical engineering students in the Junior and Senior years of study who show strong promise of success in their chosen field as evidenced by excellence of scholarship and character.

Tau Beta Pi
Faculty Advisor: Professor A. Taflove

Tau Beta Pi is a national scholastic honorary engineering fraternity which recognizes scholastic achievement and character among engineering students. Membership is by invitation to students in their Junior and Senior year of study in the McCormick School.

Northwestern University Amateur Radio Society (W9BGX)
Faculty Advisors: Professors A. V. Sahakian and A. Taflove

NUARS was formed in 1949 under the auspices of what is today known as the IEEE. In 2003, the club station was upgraded, including erecting a new H.F. seven-element beam antenna. The primary purpose of the club is to give members of the Northwestern community the opportunity to operate an amateur radio while at school. There are also many opportunities for experimental work (including circuit design and fabrication), message handling, working DX (amateurs in distant lands around the globe), award chasing, and antenna experimentation. Facilities are available for transmitting CW, SSB, AM, FM, and digital packet on various amateur frequencies available between 3 and 450 MHz. Membership is open to all Northwestern students, faculty, and staff, although only licensed members may operate the transmitting equipment. Electrical Engineering students with an interest in communications and experimentation are especially encouraged to join.
7. Laboratory and Computer Facilities

The EECS Department has well-equipped instruction and research laboratories for electronic circuits, digital circuits, solid-state electronics, biomedical electronics, communications, microwave techniques, real-time control systems, holography, fiber-optics, coherent light optics, digital systems design, computer vision, and robotics.

In addition, the Department has excellent computing facilities, with most of its computers upgraded in the last three years and all of its computers linked to Northwestern's ever-evolving high-speed backbone network connection to the internet. Specifically, the Center for Parallel and Distributed Computing has several Sun workstations, a Sun Enterprise 250 fileserver, a 16-processor IBM SP-2 distributed-memory message-passing multicomputer, an 8-processor IBM J-40 shared-memory multiprocessor, an 8-processor SGI Origin 2000 distributed shared-memory multiprocessor, and several PCs. These are connected via a high-speed fast ethernet network.

The Wilkinson Computing Lab has several powerful Sun and Redhat Linux servers, 28 high-performance Sun workstations, and 16 Windows XP PCs. A wide variety of graphics, CAD, circuit design/simulation, database, and other software packages are available on these machines.

The Ford Motor Company Engineering Design Center is our new state-of-the-art teaching facility. New designs will come to life at the center. Presented with real-world problems from clients, students can work their ideas out in the CADD (computer-aided drafting and design) lab and rapid prototyping area located on the sub-basement level and then move those plans up to the basement-level “factory floor.” The large flexible, barrier-free workspace with its concrete floor is where designs actually get built. Students can use the design prototyping lab and fabrication facilities, which include machinery such as lathes, milling machines and large saws, to build design projects both large and small.

The Ford building also features a vehicle testing area, a mechatronics lab for building circuit boards, a 60-seat classroom, a conference room, research labs, group study rooms, project display areas and a student commons area. Faculty from the department of Electrical Engineering and Computer Science have offices on the third floor.
8. Department Faculty

ACADEMIC FACULTY

Randall A. Berry, Assistant Professor, Ph.D., Massachusetts Institute of Technology, Recipient of NSF CAREER award.
Research interests: Wireless communication, data networking, and information theory.

Larry Birnbaum, Associate Professor, Ph.D., Yale University, Intelligent information
Research interests: systems, artificial intelligence, human-computer interaction, natural language processing, semantics

Fabian Bustamante, Assistant Professor, Ph.D., Georgia Institute of Technology,
Research interests: Experimental systems, with a focus on operating systems, distributed and parallel computing

Arthur R. Butz, Associate Professor; Ph.D., University of Minnesota.
Research Interests: Digital signal processing, median and related filtering.

Yan Chen, Assistant Professor, Ph.D., University of California at Berkeley.
Research interests: Computer networking and large-scale distributed systems, network measurement, diagnosis, and security, overlay and peer-to-peer systems

Alok Choudhary, Professor; Ph.D., University of Illinois at Urbana-Champaign, Recipient of an NSF PYI award.
Research interests: High-performance computing and storage, compiler and runtime systems for HPC and embedded power-aware systems, parallel data mining and databases.

Brian Dennis, Assistant Professor (and Journalism), Ph.D., University of California, Berkeley.
Research interests: Programming language design and implementation, hypermedia systems, mobile and handheld computing

Robert P. Dick, Assistant Professor; Ph.D., Princeton University, Recipient of NSF CAREER award.
Research interests: Embedded systems, design automation, probabilistic optimization algorithms, ad-hoc wireless networks

Peter Dinda, Assistant Professor, Ph.D., Carnegie Mellon University.
Research interests: Distributed systems, distributed interactive applications, networking, resource demand and availability prediction, performance analysis, statistical analysis and prediction

Daniel Edelson, Associate Professor (and Education and Social Policy). Ph.D., Northwestern University.
Research interests: Design of educational software; data visualization and analysis software for learners; inquiry-support environments for learners; motivation and learning.
Kenneth Forbus, Professor, Ph.D., Massachusetts Institute of Technology.
Research interests: Qualitative physics, analogical reasoning and learning, cognitive simulation, sketching as an interface modality, AI-based articulate virtual laboratories and modeling environments for education, computer game design

Randy Freeman, Associate Professor; Director, Center for Dynamic Systems and Control; Ph.D., University of California, Santa Barbara. Recipient of an NSF CAREER award.
Research Interests: Nonlinear control systems, robust control, adaptive control, optimal control, game theory.

Louis Gomez, Professor (and Education and Social Policy), Ph.D., University of California, Berkeley.
Research interests: Human-computer interfacing, application of computing and networking to learning

Bruce Gooch, Assistant Professor, Ph.D., University of Utah.

Dongning Guo, Assistant Professor, Ph.D., Princeton University.
Research Interests: Wireless communications, information theory, communication networks, signal processing.

Abraham H. Haddad, Henry and Isabelle Dever Professor, Director of MITP; Ph.D., Princeton University, Fellow of IEEE. Fellow of AAAS.
Research Interests: Stochastic systems, modeling, estimation, detection, nonlinear filtering, singular perturbation, applications to communications and control.

Kristian Hammond, Professor, Ph.D., Yale University.
Research interests: Science case-based reasoning - understanding the role of examples and experience in reasoning; how encapsulated experience, or cases, can be used to inform planning, problem solving, and the control of action; how examples can be used in information retrieval and in communicating preferences to a machine

Lawrence J. Henschen, Professor; Ph.D., University of Illinois at Urbana-Champaign.
Research Interests: Automated reasoning, theorem proving, meta-reasoning, deductive databases, heterogenous/distributed database systems, visual aids for programming.

Seng-Tiong Ho, Professor; Ph.D., Massachusetts Institute of Technology, Recipient of an NSF CAREER Award, Fellow of OSA.
Research Interests: Photonic device integration, DWDM chip technology, IV-V device modeling, nanoscale photonic device technology, micro-optics technology, organics and inorganics electro-optic modulators, quantum and non-linear optics.

Michael Honig, Professor; Ph.D., University of California, Berkeley. Fellow of IEEE.
Research Interests: Digital communications, wireless communications, networks, signal processing.
Ian Horswill, Associate Professor, Ph.D., Massachusetts Institute of Technology.
Research interests: Autonomous agents, robotics and computer vision, cognitive architecture and situated agency and biological modeling

Yehea Ismail, Assistant Professor, Ph.D., University of Rochester. Recipient of NSF CAREER award.
Research Interests: High performance VLSI circuits, simulation and analysis techniques for VLSI design, deep-submicron VLSI design, inductance modeling

Russ Joseph, Assistant Professor, Ph.D., Princeton University.
Research Interests: Computer architecture and power-aware computer systems including techniques for monitoring, characterizing, and optimizing performance and power consumption.

Ming-Yang Kao, Professor, Ph.D., Yale University.
Research interests: Design, analysis, applications and implementation of algorithms. Specific application areas include: computational biology, computational finance, and e-commerce. Specific algorithm areas include: combinatorial optimization, online computing, and parallel computing

Aggelos K. Katsaggelos, Professor, Director, Motorola Center for Telecommunications Research; Ph.D., Georgia Institute of Technology. Fellow of IEEE.
Research Interests: Image and video recovery and compression, multimedia signal processing, computational vision, image and video restoration.

Prem Kumar, SBC Professor of Information Technology; Director, Center for Photonic Communications and Computing; Ph.D., State University of New York, Buffalo, Fellow of OSA, Fellow of APS, Fellow of IEEE.
Research Interests: Quantum and nonlinear optics, laser and atomic physics, fiber-optic communications, networks

Aleksandar Kuzmanovic, Assistant Professor, Ph.D., Rice University.
Research interests: High-speed networks, network security, multimedia communication, resource management and control in large-scale networks, network measurement and analysis

Chung-Chieh Lee, Professor; Ph.D., Princeton University.
Research Interests: Digital communications, communication network performance modeling and analysis, distributed multi-sensor detection and estimation

Xu Li, Assistant Professor, joint appointment with the Department of Biomedical Engineering, Ph.D., University of Wisconsin-Madison.
Research Interests: computational and experimental electromagnetics, microwave imaging and sensing techniques for biomedical applications, optical imaging and diagnosis techniques for biomedical applications, propagation and scattering of electromagnetic waves in random media, especially in biological tissues, nanophotonic devices, ultrawideband antennas, image reconstruction and signal processing algorithms
Wei-Chung Lin, Associate Professor; Ph.D., Purdue University.  
**Research Interests:** Computer vision, pattern recognition, neural networks, and computer graphics.

Gokhan Memik, Assistant Professor; Ph.D., University of California, Los Angeles.  
**Research Interests:** Computer Architecture, embedded systems, compilers, design automation

Seda Ogrenci Memik, Assistant Professor, Ph.D., University of California, Los Angeles.  
**Research Interests:** Computer-aided design for VLSI, reconfigurable computing, synthesis for programmable systems

Hooman Mohseni, Assistant Professor, Ph.D., Northwestern University.  
**Research Interests:** Low-dimensional devices, quantum dots, nano-photonics, novel opto-electronic devices, novel integration methods for photonic integration circuits (PIC), advanced optical modulators

Jorge Nocedal, Bette and Neison Harris Professor of Teaching Excellence, Deputy Director of Optimization Technology Center; Ph.D., Rice University.  
**Research Interests:** Nonlinear optimization, applied linear algebra, numerical analysis, software development for numerical computations.

Don Norman, Professor, Ph.D., University of Pennsylvania.  
**Research interests:** The human side of computer science. Products. The Human-centered Design Process. Society and Technology. Using technology to make the world more humane, whether in education, business, entertainment, or the home. Design, especially of physical objects with embedded computation and telecommunication

Thrasos Pappas, Associate Professor, Ph.D., Massachusetts Institute of Technology.  
**Research Interests:** Image processing, multi-dimensional signal processing.

Brian Pardo, Assistant Professor, Ph.D., University of Michigan.  
**Research interests:** Application of machine learning, probabilistic natural language processing, computer music, and search techniques to auditory user interfaces for HCI

Mary R. Phillips, Associate Professor, Ph.D., Massachusetts Institute of Technology.  
**Research Interests:** Lightwave communication techniques and cross-talk in wavelength division systems for cable TV networks.

Martin A. Plonus, Professor; Ph.D., University of Michigan, Fellow of IEEE.  
**Research Interests:** Electromagnetic theory, propagation and scattering of electromagnetic waves, optical communication through the turbulent atmosphere, consumer electronics.

Manijeh Razeghi, Walter P. Murphy Professor and Director of Center for Quantum Devices; Ph.D. and ES-Science Doctorate, University of Paris, Fellow of OSA, Fellow of the Society of Photo-Optical Instrumentation Engineers  
**Research Interests:** Compound semiconductor science and technology; theory, epitaxy, characterization, modeling and fabrication of quantum structures and devices operating from ultraviolet (200 nm) up to far-infrared (20 µm).
Christopher Riesbeck, Associate Professor, Ph.D., Stanford University.  
**Research interests:** Educational change through the development of tools for authoring and delivering interactive learning scenarios, and tools for asynchronous efficient high-quality mentoring

Alan V. Sahakian, Professor and C. D. McCormick Professor of Teaching Excellence, joint appointment with the Department of Biomedical Engineering; Ph.D., University of Wisconsin.  
**Research Interests:** Instrumentation, signal and image processing for medical and aerospace applications, automatic detection and treatment of atrial cardiac arrhythmias by implanted devices.

Peter Scheuermann, Professor; Ph.D., State University of New York, Stony Brook, Fellow of IEEE.  
**Research Interests:** Physical database design, pictorial databases, parallel I/O systems, parallel algorithms for data-intensive applications, distributed database systems.

Selim M. Shahriar, Associate Professor; Ph.D., Massachusetts Institute of Technology.  
**Research Interests:** Applications of optically induced spin transitions, nanolithography, optical data storage, and optical phase conjugation.

Allen Taflove, Professor and C. D. McCormick Professor of Teaching Excellence; Ph.D., Northwestern University, Fellow of IEEE, named to “Highly Cited” list of Institute for Scientific Information.  
**Research Interests:** Theory and applications of computational electrodynamics, especially finite-difference time-domain (FDTD) solutions of Maxwell’s equations.

Jack Tumblin, Assistant Professor, Ph.D., Georgia Institute of Technology.  
**Research interests:** Human visual perception of intensity, movement, form and color; computer graphics; visual appearance; surface modeling; computational geometry; image-based rendering; image processing; and computer vision

Benjamin Watson, Assistant Professor, Ph.D., Georgia Institute of Technology.  
**Research interests:** Computer graphics, human computer interfaces, virtual reality, interactive simulation and gaming, visualization, model simplification

Bruce Wessels, Chairman and Walter P. Murphy Professor; Ph.D., Massachusetts Institute of Technology, Fellow of the American Physical Society and ASMI, joint appointment with the Department of Materials Science and Engineering.  
**Research Interests:** Opto-electronic integrated circuits, Compound semiconductors, electro-optic thin films and devices, MOCVD processing of ceramic superconductors and ferro-electrics.

Uri Wilensky, Associate Professor, Associate Professor (and Education and Social Policy). Ph.D., Massachusetts Institute of Technology.  
**Research interests:** Multi-agent modeling, modeling and simulation, networked simulation environments, parallel algorithms
Chi-haur Wu, Associate Professor; Ph.D., Purdue University.

Ying Wu, Assistant Professor; Ph.D., University of Illinois, Urbana-Champaign, Recipient of an NSF CAREER award.
Research Interests: Computer vision and graphics, image and video processing, vision-based human-computer interaction, machine learning and pattern recognition, multimedia, multimodal human-computer interactions, virtual environments, robotics.

Horace P. Yuen, Professor; D.Sc., Massachusetts Institute of Technology, Recipient of 1996 Quantum Communication Award, joint appointment with the Department of Physics and Astronomy.
Research Interests: Optical communication, theoretical quantum optics, measurement theory, physical cryptography.

Hai Zhou, Assistant Professor; Ph.D., University of Texas at Austin. Recipient of NSF CAREER award.
Research Interests: VLSI design automation including physical design, logic synthesis, and formal verification.

FACULTY WITH COURTESY APPOINTMENTS

Alvin Bayliss, Professor (joint with Engineering Sciences and Applied Math) and Charles Deering McCormick Chair in Teaching Excellence; Ph.D., New York University.
Research Interests: Numerical analysis, large-scale scientific computing, combustion, computational fluid dynamics, solid mechanics, acoustics.

Justine Cassell, Professor of Communication Studies. Ph.D. University of Chicago.
Research interests: Discourse and dialogue, nonverbal behavior generation and understanding, natural language generation, human-computer interaction, interactive technology for young children, embodied conversational agents.

Robert Chang, Professor (joint with Material Sciences and Engineering) Ph.D., Princeton University.
Research Interests: Thin films for electronic and optoelectronic device applications, diamond films, high Tc superconductors.

Kemi Jona, Associate Professor. Ph.D., Northwestern University.
Research interests: Basic design research on learning architectures; effectiveness of new curriculum structures based on these learning architectures across a range of subject areas and audiences; investigation of knowledge-rich, learning architecture-specific tools and technologies.

Andrew E. Kertesz, Professor (joint with Biomedical Engineering); Ph.D., Northwestern University.
Research Interests: Binocular information processing and oculomotor control by the human visual system, medical instrumentation.
John Ketterson, Fayerweather Professor (joint with Physics), Ph.D., University of Chicago, Fellow, American Physical Society.  
**Research Interests:** Condensed matter physics, novel thermonuclear materials, nanostructured magnetic, optical, metallic, and semiconducting materials, nonlinear optical and excitonic materials, Josephson-junction devices.

Samuel A. Musa, Professor and Associate Vice President for Strategic Initiatives; Ph.D., Harvard.  
**Research Interests:** Nonlinear systems, display technology, command, control and communications, and technology management.

Andrew Ortony, Professor of Education and Social Policy and of Psychology. Ph.D., University of London.  
**Research interests:** Task Emotion and cognition; Knowledge representation and figurative language comprehension; Human-computer interaction and interface design

Mort Rahimi, Professor and Vice President for Information Systems and Technology; Ph.D., University of Iowa.  
**Research Interests:** Artificial languages, computer networks, IT management.

**EMERITUS FACULTY**

James A. Aagaard, Emeritus Professor; Ph.D., Northwestern University.  
**Research Interests:** Real-time information retrieval, operating systems, database systems.

Morris E. Brodwin, Emeritus Professor; Ph.D., Johns Hopkins University.  
**Research Interests:** Electromagnetic characterization and thermal processing of high technology materials.

Max Epstein, Emeritus Professor; Ph.D., Illinois Institute of Technology.  
**Research Interests:** Applications of lasers and optical fibers in medical instrumentation and electro-optic devices and systems.

John E. Jacobs, Emeritus Professor, Ph.D., Northwestern University, Member of National Academy of Engineering.  
**Research Interests:** Advanced instrumentation for nondestructive testing in both industrial and biological fields.

Carl R. Kannewurf, Emeritus Professor; Ph.D., Northwestern University.  
**Research Interests:** Electronic materials: electrical and optical phenomena in semiconductors and metals, high Tc superconductors, low-dimensional materials and devices; thermoelectric refrigeration materials.

Gilbert K. Krulee, Emeritus Professor; Ph.D., Massachusetts Institute of Technology.  
**Research Interests:** Natural language systems, two-level grammars, intelligent support systems.
Gordon J. Murphy, Emeritus Professor; Ph.D., University of Minnesota, Fellow of IEEE. 
**Research Interests:** Integrated computer-control systems, automated manufacturing systems, digital signal processing, microprocessor-based systems.

Zenonas V. Rekasius, Emeritus Professor; Ph.D., Purdue University.
**Research Interests:** Dynamic systems stability, optimization, identification, analysis of large-scale systems.

James E. Van Ness, Emeritus Professor; Ph.D., Northwestern University, Fellow of IEEE. Member of the National Academy of Engineering.
**Research Interests:** Use of the computer to study large dynamic systems, numerical analysis, control systems, power systems.

**RESEARCH FACULTY**

Vladimir Grigoryan, Research Assistant Professor, Ph.D., Institute of Radio Engineering and Electronics, Russian Academy of Sciences, Moscow
**Research interests:** Optics communications, high speed long-haul fiber communication systems, nonlinear optics, optical solitons and autosolitons, photonic processing, resonant nonlinear interactions of laser radiation with single atoms and molecules, quantum electronics

Tom Hinrichs, Research Assistant Professor, Ph.D., Georgia Institute of Technology.
**Research interests:** Analogical and case-based reasoning, qualitative reasoning, performance support for engineering design

Patrick Kung, Research Assistant Professor; Ph.D., Northwestern University.
**Research Interests:** Compound semiconductors and optoelectronic devices.

Wei-Keng Liao, Research Assistant Professor, Ph.D., Syracuse University.
**Research Interests:** High-performance computing systems, parallel input/output system design, implementation and evaluation of radar signal processing applications on HPC systems.

Erick Michel, Research Assistant Professor, Ph.D., Northwestern University
**Research interests:** Type II superlattice compound semiconductors for optoelectronic devices (photodetectors, LEDs, lasers) operating in the Mid- to Very-Long wavelength Infrared spectral region

Steven Slivken, Research Assistant Professor; Ph.D., Northwestern University.
**Research Interests:** Growth and fabrication of III-V semiconductors for use in optoelectronic devices, including quantum cascade lasers, QWIPs, type-II InAs/GaSb lasers/detectors, and quantum dot lasers/detectors.

Richard A. Waltz, Research Assistant Professor; Ph.D., Northwestern University.
**Research Interests:** Optimization, numerical analysis, scientific computing. Applications of optimization to chip placement. Numerical software.
9. Detailed Course Descriptions

The following pages provide detailed up-to-date course descriptions of various graduate level (300 and 400 level) courses offered by the EECS department for the three programs of study in the department. Each course description provides a course title, brief course description, required and recommended texts, course directors, course prerequisites, detailed course outlines, course objectives, descriptions of homework or assignments and exams, approximate grading methods. This information will be updated every year.
COURSE TITLE: ECE 303 Advanced Digital Logic Design

CATALOG DESCRIPTION: Overview of digital logic design. Implementation technologies, timing in combinational and sequential circuits, EDA tools, basic arithmetic units, introduction to simulation and synthesis using VHDL.


REFERENCE TEXTS:

COURSE COORDINATOR: Robert Dick

COURSE GOALS: To teach design and synthesis of two-level/multilevel combinational logic as well as finite state machine design, optimization, and synthesis. Material reinforced with the use of contemporary EDA tools. Introduces the use of a hardware-description language (VHDL).

PREREQUISITE: ECE 203

PREREQUISITES BY TOPIC:
1) Number systems
2) Logic simplification using Boolean algebra and Karnaugh maps
3) Combinational logic implementation using AND/OR/NOT, NAND/NOR gates, PLAs
4) Exposure to MSI components, e.g., adders, decoders, and multiplexers.
5) Exposure to memory elements and flip-flops
6) Basic FSM design experience
7) Registers, counters, and other basic sequential devices

DETAILED COURSE TOPICS:
Week 1: Introduction to logic design: class administration, digital design methodology, introduction to Mentor Graphics tools, review of Boolean algebra and two level minimization: logic gates, Boolean algebra review, two level minimization, Karnaugh maps.

Week 2: Two level logic minimization algorithms: Unate covering, Quine McCluskey Method, CAD tools for two level minimization, ESPRESSO algorithm.

Week 3: Combinational logic implementation technologies: programmable logic arrays, MOS transistor logic, multiplexers, decoders, ROMS, field programmable gate arrays (FPGAs). Delays and timing in multilogic logic synthesis: gate delays, timing waveforms, static/dynamic hazards and glitches, designs to avoid hazards.

Week 4: Multilevel logic synthesis: Mapping 2-level logic to NANDs and NORs, CAD tools for multilevel logic, Factoring, Extraction, Simplification. Arithmetic Logic
Circuits: review of number systems, Adders, ripple carry, carry lookahead, carry select adders, combinational array multipliers, ALUs, general function units. Binate covering and technology mapping.

**Week 5:** Memory elements and clocking: Sequential logic networks, latches, flip-flops, timing issues, setup and hold times. Registers and counters: Registers, register files, counters, designs of counters with various flip flops.

**Week 6:** Memory Design: Random Access Memory (RAMS), Static RAMS, Dynamic RAMS, Memory Organizations, Read Only Memories (ROM).

**Week 7:** Finite State Machine Design: Review of state machine design, Moore/Mealy machine, finite state machine word problems. Transformation from non-deterministic representations. Finite State Machine Optimization: Motivation for FSM Optimization, state minimization algorithms, implication chart method, CAD tools for optimization.

**Week 8:** Finite State Machine Assignment: motivation for state assignment, example for state assignment, paper and pencil methods for state assignment, one-hot encodings, EDA tools for state assignment. Finite State Machine Implementations: Mapping FSM to random logic, ROMs, PLAs, and FPGAs.

**Week 9:** Introduction to VHDL: VHDL language basics, interface, architecture body, behavioral VHDL, process statements, delay models. VHDL Structural Modeling: Review of VHDL, structural VHDL modeling, use of hierarchy, combinational designs, component instantiation, concurrent statements, test benches.

**Week 10:** VHDL Modeling of Sequential Machines: Describing sequential behavior in VHDL, latches, flip-flops, FSMs, synthesis using VHDL, packages in VHDL. Case Study of VHDL design, overview of design, VHDL behavioral design, VHDL structural design.

**COMPUTER USAGE:** Students learn to use industrial EDA tools from Mentor Graphics and Synopsys. Specifically, they use the tools, Design Architect for schematic capture, QuickSim-II for gate level logic simulation, ModelSim for VHDL simulation, and Design Compiler for VHDL synthesis. Students use the Unix workstations in the ECE Wilkinson lab. In addition, students also use the SIS synthesis tools.

**HOMEWORK ASSIGNMENTS:**

**Homework 1:** Design problems dealing with two level logic minimization using Boolean algebra, Karnaugh Maps, Quine McCluskey method.

**Homework 2:** Design problems dealing with multilevel logic synthesis, combinational logic implementations using PLAs, multiplexers, CMOS transistors, delays and timing in combinational logic.

**Homework 3:** Finite state machine design.

**Homework 4:** Finite state machine word problems. Non-deterministic specifications. Efficient state minimization and assignment.

**Homework 5:** Comprehensive course review homework assignment.

**LABORATORY PROJECTS:**

**Lab 1:** Introduction to the use of the Mentor Graphics tools. Use of Design Architect schematic entry system, the QuickSim-II logic simulator.

**Lab 2:** Use of ESPRESSO for two-level minimization.

**Lab 3:** Use of MIS for multi-level minimization.
Lab 4: Use MIS and Mentor Graphics tools to design and simulate a finite state machine capable of repairing a damaged video controller circuit.

Lab 5: Use Mentor Graphics ModelSim and Synopsys Design Compiler for finite state machine simulation and synthesis.

GRADES:
Homework assignments - 25%
Lab assignments - 25%
Midterm exam - 20%
Final exam - 30%

COURSE OBJECTIVES: Students completing this course should be able to

1) Do two-level logic minimization using Boolean algebra, Karnaugh maps, the Quine McCluskey method, and the Espresso software;
2) Do multi-level logic simplification using factoring and the MIS software;
3) Understand and use advanced technology mapping algorithms;
4) Understand advanced two-level minimization heuristics;
5) Design using a variety of implementation technologies, e.g., PLAs, multiplexors, CMOS transistors, and field-programmable gate arrays;
6) Draw and interpret timing diagrams;
7) Identify and accelerate a circuit's critical timing path;
8) Do efficient FSM state minimization, assignment, and splitting;
9) Design various arithmetic, logic, and memory components, e.g., ALUs, shifters, decoders, multiplexers, RAMs, and ROMs;
10) Design combinational and sequential circuits using VHDL;
11) Use a research-quality EDA software to perform two-level combinational logic minimization, multilevel combinational synthesis, state minimization, and state assignment of sequential logic; and
12) Use industrial EDA tools for schematic capture, gate-level logic simulation as well as HDL simulation and synthesis.
COURSE TITLE: ECE 307 Communications Systems

CATALOG DESCRIPTION: Analysis of analog and digital communications systems, including modulation, transmission, and demodulation of AM, FM, and TV systems. Design issues, channel distortion and loss, bandwidth limitations, additive noise.


REFERENCE TEXT: none

COURSE DIRECTOR: M. Honig

COURSE GOALS: To teach the principles underlying modulation and demodulation of analog signals along with associated system design issues. The latter includes power and bandwidth constraints and performance in the presence of additive noise.

PREREQUISITES BY COURSES: ECE 222 and ECE 302

PREREQUISITES BY TOPIC:

1: Fourier transforms and linear systems
2: Probability and random variables

DETAILED COURSE TOPICS:

Week 1. Components of a communications system, benefits of modulation, review of Fourier series and Fourier transform.
(READINGS: Z&T, Chapter 1, 2.1, 2.2, 2.4, 2.5)

(READINGS: Z&T, 2.5 (cont.), 2.7 (excluding 2.7.13-14))

Week 3. Cross-correlation and autocorrelation of deterministic signals, power spectral density, Hilbert transform.
(READINGS: Z&T, 2.6, 2.9.1-2)

Week 4. Analytic signals, characterization of bandpass signals, double-sideband and amplitude modulation.
(READINGS: Z&T, 2.9.3-5, 3.1 up to ``Single-Sideband Modulation")

(READINGS: Z&T, 3.1 from SSB subsection up to ``Frequency Translation and Mixing")
Week 6. Phase and frequency modulation, spectral analysis, FM bandwidth, demodulation of FM.
(READINGS: Z&T, 3.2)

Week 7. Superheterodyne receiver, multiplexing, probability review.
(READINGS: Z&T, Sec. 3.1.5, 3.7, Chapter 4)

Week 8. Probability review (cont.): densities, random variables, and statistical averages; random processes, first- and second-order statistics, stationarity and ergodicity.
(READINGS: Z&T, Chapter 4, 5.1, 5.2)

(READINGS: Z&T, 5.3, 5.4)

Week 10. Narrowband noise, Signal-to-Noise Ratio analysis of DSB and coherent AM.
(READINGS: Z&T, 5.5.1-2, 6.1)

**HOMEWORK ASSIGNMENTS:**
Homework 1: Problems on using properties of the Fourier transform to evaluate transforms of specific signals.

Homework 2: Problems on characterizing linear, time-invariant filters and input-output relations.

Homework 3: Problems on computing the Hilbert transform, autocorrelation, and power spectral density.

Homework 4: Problems on characterizing bandpass signals and determining properties (e.g., modulation index and transmitted power) of double-sideband and amplitude-modulated signals.

Homework 5: Problems on Amplitude and Single-Sideband modulation and demodulation (e.g., computing power efficiency and determining spectral properties).

Homework 6: Problems on phase and frequency modulation and demodulation (e.g., computing the spectrum for tone modulation and determining bandwidth).

Homework 7: Problems on superheterodyne receivers (e.g., filter specification and determining tuning range), and on random variables.

Homework 8: Problems on statistical averages, second-order statistics, and ergodicity.

Homework 9: Problems on computing power spectral densities, effect of filtering, and characterizing narrowband noise.

**COMPUTER PROJECTS:** none
LABORATORY PROJECTS:
1. Uses Hypersignal software on a PC to view signals in the time and frequency domains. The software simulates an oscilloscope and spectrum analyzer. The effects of filtering and modulation are demonstrated.

2. The students build an amplitude modulator based on the Motorola MC1496 modulator chip, along with a noncoherent demodulator. The outputs of the modulator and demodulator are viewed in the time and frequency domains.

3. The students build a frequency modulator and demodulator based on the Exar XR-2207 voltage-controlled oscillator and Exar XR-221 phase-locked loop demodulator. The output of the modulator is viewed in the time and frequency domains, and performance of the demodulator is observed.

GRADES:
Homework: 15%
Labs: 15%
Midterms (2): 30%
Final: 40%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Evaluate and interpret Fourier transforms of signals by using properties of the Fourier transform.

2. Evaluate the output of a linear, time-invariant system given an input and the impulse response or transfer function.

3. Evaluate the autocorrelation and energy or power spectral density of a deterministic signal.

4. Evaluate the Hilbert transform of elementary signals.

5. Characterize a bandpass signal in terms of in-phase and quadrature components, envelope, and phase.

6. Characterize double-sideband and amplitude modulated waveforms in the time and frequency domains.

7. Characterize double-sideband, amplitude, and single-sideband modulation in terms of bandwidth and power efficiency.

8. Describe phase and frequency modulated signals in the time domain, and tone modulated signals in the frequency domain.
9. Estimate the bandwidth of a phase or frequency modulated waveform.

10. Determine filter specifications and tuning range for a superheterodyne receiver.

11. Determine whether or not a random process is wide-sense stationary and ergodic.

12. Compute the power spectral density of a random process.

13. Compute the autocorrelation and power spectral density of a filtered random process.

14. Specify narrowband noise in terms of low-pass random noise.

15. Compute pre- and post-detection Signal-to-Noise Ratios for linear modulation systems.

**ABET CONTENT CATEGORY:** 100% Engineering (Design component).
COURSE TITLE: ECE 308 Advanced Electromagnetics and Photonics

CATALOG DESCRIPTION: Electromagnetic waves, transmission lines; impedance transformation; transients on lines; wave reflection and transmission; metallic waveguides and wave transmission; antenna and diffraction, antenna arrays, communication, and radar.

REQUIRED TEXTS:
Edminister, Schaum’s Outline of Theory and Problems of Electromagnetics, McGraw-Hill.

COURSE COORDINATOR: Horace Yuen

COURSE GOALS: To provide the electrical engineering student with detailed information regarding key applications of electromagnetic fields and waves in modern communications technology, especially antennas, fiber optics and photonic devices.

PREREQUISITE: ECE 224

ORGANIZATION: Three lectures per week with weekly labs. Weekly homework assignment.

DETAILED COURSE TOPICS:

<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Review of Maxwell’s equations and plane wave propagation. Review of plane wave reflection and transmission at normal incidence</td>
</tr>
<tr>
<td>2</td>
<td>Review of transmission lines, transients</td>
</tr>
<tr>
<td>3</td>
<td>Plane wave reflection and transmission at oblique incidence.</td>
</tr>
<tr>
<td>4</td>
<td>Geometric optics. Images formed by mirrors and lenses.</td>
</tr>
<tr>
<td>8</td>
<td>Radiation and antennas, continued: Aperture antennas. Antenna arrays.</td>
</tr>
<tr>
<td>10</td>
<td>Contemporary photonic devices, including micron-scale waveguides, couplers, resonators, photonic bandgap structures, and lasers.</td>
</tr>
</tbody>
</table>
LABORATORY PROJECTS:

Week 2. Transients on transmission lines, part 1.
Week 3. Transients on transmission lines, part 2.
Week 4. Sinusoidal excitation of transmission lines, part 1.
Week 5. Sinusoidal excitation of transmission lines, part 2.
Week 6. Propagation in unbounded media.
Week 7. Interference in electromagnetic waves.
Week 8. Sinusoidal excitation of waveguides.
Week 9. Propagation below cutoff frequency.

GRADES:  Midterm – 30%
           Final – 60%
           Homework – 10%

COURSE OBJECTIVES: When a student completes this course, s/he should understand:

1) Key aspects of the behavior and design of antennas for wireless communications systems, including satellite direct-broadcast and terrestrial cellular / personal communications systems.

2) Propagation and cutoff behavior of electromagnetic wave modes in metal waveguides comprised of parallel plates, rectangular pipes, and circular pipes.

3) Waveguiding phenomena for light in optical fibers.

4) Electromagnetic phenomena associated with contemporary photonic devices, including micron-scale waveguides, couplers, resonators, photonic bandgap structures, and lasers.

ABET CONTENT CATEGORY: 100% Engineering (Design component).
COURSE TITLE: ECE 328 Numerical Methods for Engineers

CATALOG DESCRIPTION: Introduction to numerical methods; numerical differentiation, numerical integration, solution of ordinary and partial differential equations. Students write programs in C++, FORTRAN, C, or Matlab using methods presented in class.


REFERENCE TEXTS: None

COURSE COORDINATOR: Jorge Nocedal

COURSE GOALS: To teach basic numerical methods required for typical engineering and business applications. Give students experience in understanding the properties of different numerical methods so as to be able to choose appropriate methods and interpret the results for engineering problems that they might encounter. Students will implement and study some of the numerical methods using C++, C, FORTRAN, MATLAB or some other high-level language. Emphasis is given to the graphical representation of results.

PREREQUISITES: GTK 205-1, 2, 3, and MATH 214-1, 2, 3. MATH 221 or GTK 205-4 may be taken concurrently.

PREREQUISITES BY TOPIC:
1. Computer programming
2. Calculus
3. Differential equations
4. Linear Algebra

DETAILED COURSE TOPICS
Week 1: Computer Arithmetic
Week 2: Linear Algebra and Matrices
Week 3: Gaussian elimination and LU factorization
Week 4: Nonlinear Equations and Optimization
Week 5: Polynomial interpolation
Week 6: Splines
Week 7: Numerical methods for integration
Week 8: Gaussian Quadrature
Week 9: Numerical Methods for Ordinary Differential Equations
Week 10: Initial value problems including stiff equations.

COMPUTER USAGE: There are five programming assignments. Students can use a PC or a workstation and are required to master a program such as MATLAB OR MATHEMATICA that will allow them to produce graphical representations of their results.

LABORATORY PROJECTS: None
GRADES:
Homework - 55 %
Midterm - 20 %
Final - 25 %

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:
1. Understand the type of numerical problem he/she is facing and relate it to one of the problem classes discussed in the course.
2. Find a numerical routine that will solve the engineering problem, or use one of the numerical tools such as MATLAB or MATHEMATICA.
3. Design a driver that will use a number of numerical routines to perform the desired task.
4. Interpret numerical results and devise graphical representations that facilitate their analysis.
5. Understand the fundamental properties of computer arithmetic. Differentiate between the errors caused by computer arithmetic and those caused by the limitations of the algorithms.
6. Predict the difficulties that may occur in solving an engineering problem due to (1) problem size (2) conditioning (3) errors in the data.
7. Understand the concepts of ill-conditioned and well posed problems, and identify important classes of problems (such as nearly singular systems of equations) that are difficult to solve.
8. Understand the tradeoffs between speed and memory, or speed and robustness that often occur in practical algorithms.

ABET CONTENT CATEGORY: 50% Math and Basic Science, 50% Engineering.
COURSE TITLE: ECE 332 Digital Image Analysis

CATALOG DESCRIPTION: Introduction to computer and biological vision systems, image formation, edge detection, image segmentation, texture, representation and analysis of two-dimensional geometric structures, and representation and analysis of three-dimensional structures.

REQUIRED TEXT: None


READINGS: Papers from journals, conference proceedings, or book chapters will be assigned.

COURSE COORDINATOR: Ying Wu

COURSE GOALS: The goal of this course is to provide students with a basic understanding of the fundamentals and applications of digital image analysis (or computer vision) techniques including 2-D and 3-D paradigms to solve real world applications.

PREREQUISITES: ECE 230

PREREQUISITES BY TOPIC:
1. Linear algebra
2. Probability
3. Computer programming in C

DETAILED COURSE TOPICS:
1. Introduction to image formation (1 week)
2. Binary image processing (2 weeks)
3. Color and color segmentation (1 week)
4. Region segmentation (1 week)
5. Edge, contour, Hough transform and texture (2 weeks)
6. Motion and tracking (1 week)
7. 3D geometry, calibration, pose and stereo (1 week)
8. Lighting and applications (1 week)

MACHINE PROBLEMS:
1. Implementation of connect component analysis
2. Implementation of morphological operators
3. Implementation of histogram equalization and lighting compensation
4. Implementation of color segmentation
5. Implementation of canny edge detector
7. Implementation of camera calibration
8. Implementation of 3D pose determination
FINAL PROJECTS:
Based on the machine problems, the course involves a final project to design a vision-based interface system, i.e., a “virtual gun,” where the cursor moves with your fingertips. The idea is to locate and track a fingertip through a video sequence accurately and robustly. The project consists of three parts: (1) a working demo, (2) a 15-minute presentation, and (3) a 15-page report.

GRADES:
Machine problems – 50%
Final project – 50%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:
1. Understand the projection geometry in the image formation process.
2. Design and implement computer programs to perform image feature extraction.
3. Design and implement computer programs for image segmentation.
4. Design and implement computer programs for motion analysis and tracking.
5. Understand the basic techniques and issues in 3-D computer vision.
6. Design and build a real vision-based interaction system.

ABET CONTENT CATEGORY: 100% Engineering (Design component).
COURSE TITLE: ECE 346 Microprocessor System Design


REQUIRED TEXTS: ECE 346 Class Notes by L. Henschen

REFERENCE TEXTS: 1. Device data sheets 2. Distributor catalogues

COURSE COORDINATOR: Larry Henschen

COURSE GOALS: The goal is to teach students how to design, build and program embedded systems.

PREREQUISITES: ECE 203 and ECE 205

PREREQUISITES BY TOPIC:
1. basic digital integrated circuits - AND/OR/NOT gates, latches, demultiplexors
2. basic structure of a processor - arithmetic registers, address registers, basic addressing modes
3. basic assembly language programming

DETAILED COURSE TOPICS
Week 1: Microcontrollers. 8051 pinout and electrical characteristics.
Week 2: Connecting to external RAM and program. Latches and demultiplexors.
Week 3: Ports. Onboard special functions – interrupts, timers, serial I/O.
Week 4: Special functions continued. Timing analysis.
Week 5: 8051 assembly programming, emulators.
Week 6: Introduction to a typical microprocessor - 8086. Basic 8086 control signals - DEN, DTR. Bi-directional bus drivers. 8224 clock circuit. 2- and 4-byte bus systems.
Week 7: Interrupt structure and the 8259 Interrupt Controller. Priority interrupt systems
Week 8: DMA.
Week 9: I²C buses and devices.
Week 10: Multibus and shared bus structures - 8289.

COMPUTER USAGE: Students use PCs to assemble and emulate programs before burning into E/EPROMs. Students use device programmers to generate 2764/2864 program chips for their projects.

LABORATORY PROJECTS:
Four labs starting from a simple micro-controller system on a breadboard and leading to a small-scale embedded application that uses most of the typical features (timers, serial IO, ADC/DAC, etc.) built into micro-controllers.
GRADES:
Homework - 10 %
Labs Assignments - 30 %
Midterm Exam - 30 %
Endterm Exam - 30 %

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Design an embedded system, including both hardware and software.
2. Decide what level of sophistication the microprocessor needs to have and what additional devices are needed based on the features of the application.
3. Determine how to connect the microprocessor, memories, and extra devices into a working system.
4. Read device-timing diagrams for processors, memories, and the like, and determine device timing compatibility.
5. Read device data sheets and pinout descriptions and understand how to wire the devices together.
6. Build an embedded system, both hardware and software, using DMA and/or interrupts.
7. Understand how to use auxiliary circuits, like latches, bus drivers and demultiplexors, to build a system.
8. Understand how to use UARTS, DAC/ADC devices, serial devices, timer/counter devices and similar devices.
9. Design the software and coordinate the software and the hardware into an integrated working system.

ABET CONTENT CATEGORY: 100% Engineering (Design component).
COURSE TITLE: ECE 347 Microprocessor System Projects

CATALOG DESCRIPTION: Programmable logic devices such as PAL, FPGA, etc. Design, prototype and test individual projects involving microprocessors and programmable logic devices.

REQUIRED TEXTS: Notes, datasheets and manuals.

REFERENCE TEXTS: 1. Device data sheets 2. Distributor catalogues

COURSE COORDINATOR: Larry Henschen

COURSE GOALS: The first goal is to teach students how to design, build, program and document embedded systems. The second goal is to teach students how to use field programmable devices in embedded system design.

PREREQUISITES: ECE 346

PREREQUISITES BY TOPIC:
1. basic digital integrated circuits - AND/OR/NOT gates, latches, demultiplexors
2. simple circuit timing and timing diagrams
3. basic computer architecture - registers, addressing modes, arithmetic, interrupts, DMA
4. microprocessor design and embedded system design
5. familiarity with related circuitry such as timer/counters, bus drivers, ADC/DACs, etc.
6. basic assembly language programming

DETAILED COURSE TOPICS
Week 1: PAL and PLA devices, lab orientation
Week 2: prototyping, breadboard vs wirewrap, practical considerations (decoupling, switching, debouncing, bus termination, differential driving for long buses)
Week 3: FPGA devices
Weeks 4-10: Specification, design, implementation, packaging and documentation of small group projects

COMPUTER USAGE: Students use PCs to assemble and emulate programs before burning into E/EPROMs. Students use device programmers to generate 2764/2864/8751 program chips for their projects.

LABORATORY PROJECTS:
1. Specify, design, implement, package and document small group projects. Students work in teams of 3-5 on a project of their own choosing or from a list provided by the instructor. The original project descriptions are typically one to two sentences, so that the teams have to work from a vague, general statement through to a completed prototype.
2. Every team must produce the following documents in addition to a working completed prototype: specification document, design document, mid-project progress report, user's manual, maintenance manual and post-mortem report.
GRADES:
Lab Assignments - 100 %

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Design an embedded system, including both hardware and software, and build a prototype.
2. Document all steps in the design and implementation process
3. Determine when and how to use field-programmable devices in a design.

ABET CONTENT CATEGORY: 100% Engineering (Design component).
COURSE TITLE: ECE 353 Digital Microelectronics

CATALOG DESCRIPTION: Logic families, comparators, A/D and D/A converters, combinational systems, sequential systems, solid-state memory, large-scale integrated circuits, and design of electronic systems.


COURSE COORDINATOR: Alan V. Sahakian

COURSE GOALS: To teach the analysis and design of electronic circuits and systems that realize logic functions. Topics include interface circuits, A/D, D/A conversion circuits, dynamic and static memory and memory systems. Interconnection considerations such as the calculation of fan-out, noise margin, interconnection delay, and transmission-line effects are stressed. Techniques for calculating the reliability of complex electronic systems based on Military Handbook 217-E are introduced.

PREREQUISITES: ECE 203 and ECE 225

PREREQUISITES BY TOPIC:
1. Circuit analysis
2. Physical electronics
3. Active devices/circuits including BJTs, FETs, and amplifiers
4. Fundamentals of logic design and computer organization

DETAILED COURSE TOPICS

1. Introduction, review of devices and their properties
2. Bipolar families
3. CMOS
4. Very high performance (Schottky, BiCMOS,IIL, etc.)
5. Tri-state logic, bus design
6. Memory technology
7. Parasitics, transmission-line effects, packaging
8. Analog to Digital interfaces
9. Linear and switching mode power conversion

COMPUTER USAGE: P-Spice is used for circuit modeling.
LABORATORY PROJECTS:

LAB #1: Measurement of Logic Family Voltage Transfer Characteristics
LAB #2: Measurement of High-Speed Switching Characteristics of Various Logic Families
LAB #4: Reliability Experiment -- Design and Testing of a Single-Error-Correcting Channel
LAB #5: A Simple Dynamic RAM
LAB #6: Transmission-Line Effects in High-Speed Logic Systems

GRADES:
There will be one midterm and a final exam. These will be based on the lectures, textbook readings, handouts, assignment problems, and the laboratory work. Tentatively, the final grade for the course will include the midterm exam, the final exam, homework problems and lab work with equal weights (25% each).

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Understand the principles of operation of several logic families, including complementary CMOS, pseudo NMOS, dynamic logic, ECL, and DTL.

2. Analyze a given gate design for the important dc and ac parameters, including the voltage transfer characteristic, the corner voltages and noise margins, the fanout or output transition waveform under load, the power dissipation, and the propagation delay.

3. Design gates in several MOS families, including transistor sizing.

4. Evaluate the reliability of an electronic system, including those incorporating redundant elements, using the methods of Military Handbook 217E.


6. Predict waveforms in systems involving logic gates and transmission lines.

7. Understand the principles of operation of static and dynamic RAM, and various forms of ROM.

8. Operate a modern high-speed oscilloscope including compensating the probe, adjusting for the correct trigger operation, and making quantitative measurements of both voltages and times.

9. Be able to debug small hardware logic systems.

ABET CONTENT CATEGORY: 100% Engineering (Design component).
COURSE TITLE: ECE 357 Introduction to VLSI CAD

CATALOG DESCRIPTION: Basic concepts in VLSI CAD with emphasis on physical design, fundamental algorithms for CAD problems, development of CAD tools.


REFERENCE TEXTS: None.

COURSE COORDINATOR: Hai Zhou

COURSE GOALS: To teach basic concepts in VLSI CAD with emphasis on physical design. To teach various fundamental algorithms and methodologies used in VLSI CAD. To introduce technology and challenges facing the industry today and in the next ten years.

PREREQUISITES: CS 311

DETAILED COURSE TOPICS:
Week 1: Introduction: modern VLSI design flow; CAD paradigms; Algorithms 101 (correctness, performance, complexity).
Week 2-3: Partitioning: hypergraph vs. graph modeling; Kernighan-Lin Heuristic; network flow based approaches.
Week 4-5: Floorplanning: slicing floorplan sizing; topology optimization by simulated annealing; analytical methods.
Week 6: Placement: objective functions; partitioning based placement.
Week 7: Global routing: geometric spanning trees; Steiner trees; net ordering.
Week 8: Detailed Routing: shortest paths and maze search.
Week 9: Channel routing.
Week 10: Layout compaction and design rule checking.

COMPUTER USAGE: Computer usage in this course is light. Some homework may involve programming tasks. A term project may be a theoretical work or an experimental work up to a student’s selection.

LABORATORY: ECE Department Workstation Lab. Accounts will be arranged. The labs consist of a collection of high-speed workstations and Mentor Graphics CAD tools for physical design (placement and routing).
GRADES:
Homework - 30%
Project - 30%
Exam - 30%
Class participations - 10%

COURSE OBJECTIVES:

1. Understand the general design process of modern VLSI chips.
2. Be able to identify and formulate design problems within a sound methodology.
3. Increase ability to analyse a problem, and design efficient algorithms to solve it.
4. Become familiar with most algorithms and methods used in VLSI CAD.
5. Be able to implement algorithms in CAD tools.

ABET CONTENT CATEGORY: 100% Engineering (Design component).
COURSE TITLE: ECE 358 Introduction to Parallel Computing

CATALOG DESCRIPTION: Introduction to parallel computing for scientists and engineers. Shared memory parallel architectures and programming, distributed memory, message-passing data-parallel architectures, and programming.


REFERENCE TEXTS:
1. I. Foster, Designing and Building Parallel Programs, Addison Wesley 1995.

COURSE COORDINATOR: Gokhan Memik

COURSE GOALS: To provide an introduction to the field of parallel computing. The goals are to provide an overview of the three basic types of parallel computing: shared memory, distributed memory message-passing, and data parallel computing, with hands-on experience with real parallel programming on actual parallel machines.

PREREQUISITES: ECE 361 and (ECE 230 or ECE 231 or CS 211)

PREREQUISITES BY TOPIC:
1. An overview of computer architecture
2. Basic concepts of processors, ALUs, memories, caches, input-output
3. Basic to intermediate concepts on programming of serial computers using C or Fortran
4. Simple concepts of data structures like arrays and link lists in programs
5. Some knowledge of scientific and engineering applications

DETAILED COURSE TOPICS:
Week 1: Introduction to parallel computing: motivation for parallel computing, options of parallel computing, economics of parallel computing, basic concepts of parallel algorithms. Introduction to parallel programming: data and task parallelism, coarse and fine grain parallelism, performance of parallel programs, load balancing and scheduling, analysis of simple parallel programs.
Week 2: Overview of shared memory parallel architectures: memory organization, interconnect organization, cache coherence, case studies of machines such as SGI Challenge, IBM J-30, HP/Convex Exemplar. Introduction to shared memory parallel programming: shared memory model, process creation and destruction, mutual exclusion, locks, barriers.
Week 4: Implicit shared memory parallel programming: use of compiler directives for parallel programming, DOALL and DOACROSS and PRAGMA directives for loop level parallelism, parallel programming examples using directives.

Week 5: Distributed memory multicomputer architectures: overview of distributed memory parallel machines, message passing schemes, store and forward versus wormhole routing, interconnection networks, case studies of parallel machines such as Intel Paragon, IBM SP-2, Thinking Machine CM-5. Global Communication operations in distributed memory machines: one-to-all broadcast, reduction, shift, scatter, gather operations, analysis of performance of above operations on various parallel architectures.


Week 7: Introduction to SIMD parallel architectures: Single-instruction multiple data stream architectures, control and data units, interconnection networks, case studies of machines such as Thinking Machines CM-2, CM-5 and Masspar MP-2. Introduction to data parallel programming: Fortran-90, array sections, array operations, array intrinsic operations.


COMPUTER USAGE: Students get hands-on parallel programming experience on 3 parallel machines at the Center for Parallel and Distributed Computing, including a 16 processor IBM SP-2 distributed memory machine, an 8 processor IBM J-40 shared memory machine, and an 8-processor SGI Origin 2000 distributed shared memory multiprocessor. In addition, students will use the machine in the Wilkinson Lab as a cluster for the final project.

HOMEWORK ASSIGNMENTS:
Homework 1: Design problems dealing with shared memory parallel programming, examples of program transformations to parallelize loops, use of explicit and implicit parallel programs using both the SGI directives and PTHREADS.
Homework 2: Design problems dealing with distributed memory message-passing parallel programming, use of MPI, analysis of communication patterns.
Homework 3: Design programs related to data parallel programming, use of High Performance Fortran, data layouts and alignments.
Homework 4: Design of parallel algorithms for various problems including matrix operations on
dense and sparse matrices, analysis of parallel algorithms.

LABORATORY PROJECTS:
Lab 1: Development of a parallel program for solving a set of linear system of equations using Gaussian Elimination using both explicit parallel programs with PTHREADS and implicit parallel programs using SGI directions, experiments on SGI Origin 2000 and IBM J-40 shared memory multiprocessors.
Lab 2: Development of a parallel program for solving a set of linear system of equations using Gaussian Elimination using message-passing parallel programming using C or Fortran with MPI message passing, and experiments on IBM SP-2 distributed memory and SGI Origin 2000 multiprocessor for portability.
Lab 3: Development of a parallel program for solving a set of linear system of equations using Gaussian Elimination using data parallel programming with High Performance Fortran and experiments on the IBM SP-2 distributed memory multiprocessor.

GRADES:
Four homeworks - 20 %
Three labs - 20 %
Midterm exam - 30%
Final exam - 30%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:
1. Solve a given problem using parallel computing. Analyze the problem for various ways of parallelization, and design the best parallel algorithm.
2. Have a broad understanding of shared memory parallel architectures and programming.
3. Design a shared memory parallel program for a given parallel algorithm using both explicit and implicit parallel programming, measure real speedups, identify bottlenecks, and devise improvements to the parallel program.
4. Have a broad understanding of distributed memory parallel architectures and programming.
5. Design a message-passing distributed memory parallel program for a given parallel algorithm using the portable Message-Passing Interface (MPI), measure real speedups, identify bottlenecks, and devise improvements to the parallel program.
6. Have a broad understanding of data parallel architectures and programming.
7. Design a data parallel program for a given parallel algorithm using High Performance Fortran (HPF), measure real speedups, identify bottlenecks, and devise improvements to the parallel program.

ABET CONTENT CATEGORY: 100% Engineering (Design component).
COURSE TITLE: ECE 359 Digital Signal Processing

CATALOG DESCRIPTION: Discrete-time signals and systems, Discrete-Time Fourier Transform, z-Transform, Discrete Fourier Transform, Digital Filters.


COURSE COORDINATOR: Thrasyvoulos N. Pappas

COURSE GOALS: To provide a comprehensive treatment of the important issues in design, implementation, and application of digital signal processing algorithms.

PREREQUISITES: ECE 222

PREREQUISITES BY TOPIC:

1. Signals and linear systems theory
2. Laplace and Fourier transform

DETAILED COURSE TOPICS:

1. Discrete-time signals and systems. Linear Time-Invariant (LTI) Systems.  
   Linear constant-coefficient difference equations.
2. Frequency domain representation of discrete-time signals and systems.  
   The Discrete-time Fourier transform.
3. The z-transform, the inverse z-Transform, z-Transform properties.
4. Sampling of continuous-time signals. Sampling Theorem. Sampling Rate Conversions.
   Linear Systems with Generalized Linear Phase.
6. FIR and IIR filters. Structures for discrete-time systems.
   The discrete Fourier transform. Linear and Circular convolution.
8. Computation of the discrete Fourier transform. Decimation-In-Time and  
   Decimation-In-Frequency FFT Algorithms.
9. FIR and IIR filter design techniques.

COMPUTER USAGE: Students use MATLAB on a platform of their choice to do problems illustrating the above topics.

LABORATORY PROJECTS: See computer usage.
GRADES:

* Homework - 30%
* Midterm - 30%
* Final - 40%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Design linear discrete-time systems and filters and analyze their behavior.
2. Represent continuous-time signals and linear systems in discrete time, so that such signals can be recovered in continuous time when necessary.
3. Compute approximations to Fourier transforms of continuous-time signals with finite discrete time methods.
4. Take advanced courses in signal processing (image, speech, audio, etc.), communications, systems and control.

ABET CONTENT CATEGORY: 100% Engineering (Design component).
COURSE TITLE: ECE 360 Introduction to Feedback Systems


REFERENCE TEXTS: None

COURSE COORDINATOR: Randy Freeman

COURSE GOALS: Students learn how the use of feedback can significantly alter the dynamic behavior of a system. They learn how to design feedback systems to meet a set of performance criteria. In the laboratory projects, they gain experience in designing controllers for a real physical system.

PREREQUISITES: ECE 222 or equivalent

PREREQUISITES BY TOPIC:
1. Transfer functions of linear time-invariant systems, poles and zeros, Laplace and Z transforms (HW Set #1)
2. Fourier transforms and Bode plots

DETAILED COURSE TOPICS

WEEK 1: anatomy of a feedback system (plant, controller, sensors, actuators, command and reference inputs, noise and disturbance inputs), advantages of feedback (sensitivity reduction, disturbance rejection, stabilization, performance improvement) linear models of physical systems. Chapter 1

WEEK 2: linear models of physical systems, converting o.d.e.'s to transfer functions, block diagram manipulations. Chapter 3 (3.1-3.2)

WEEK 3: stability and the final value theorem, steady-state analysis, tracking error reduction via proportional control, step response of first- and second-order systems (time constant, natural and damped frequency, damping ratio). Chapter 3 (3.3)

WEEK 4: design specifications vs. pole/zero locations (overshoot, rise time, settling time). Chapter 3 (3.4-3.5)

WEEK 5: PID control, integrator windup, tracking and system type. Chapter 4

WEEK 6: Routh-Hurwitz stability criterion and root locus diagrams. Chapter 3 (3.6) and Chapter 5
WEEK 7: root locus controller design methods (proportional and lead/lag controllers). Chapter 5 (5.5)

WEEK 8: Nyquist stability criterion, Bode plots, gain/phase margins, bandwidth, crossover frequency, minimum-phase systems and Bode's gain/phase relationship. Chapter 6

WEEK 9: frequency domain controller design methods (proportional and lead/lag controllers), sensitivity/complementary sensitivity. Chapter 6 (6.7)

WEEK 10: digital implementations of analog controllers (impulse/step/ramp invariant approximations, Tustin/bilinear approximations, matched pole-zero approximations). Chapter 8 (8.3)

COMPUTER USAGE: Matlab

LABORATORY PROJECTS: seven lab sessions introduce students to control system simulation as well as the real-time control of an electro-mechanical system.

Lab 1: Introduction to the New C60 Laboratory. Appendix A: Model of Torsional Disk System
Lab 2: Introduction to Digital Simulations
Lab 3: Introduction to the Control of the Torsional Disk System. Appendix B: ECP Executive Software. Appendix C: ECP Safety Precautions
Lab 4: PD Control
Lab 5: PID Control
Lab 6: Root Locus Design
Lab 7: Frequency Response of the Disk System

GRADES:
Homework - 10%
Labs - 30%
Midterm - 25%
Final - 35%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:
1. derive closed-loop transfer functions from block diagrams of interconnected subsystems. (HW Set #2)
2. derive time-domain response characteristics and translate time-domain design specifications into frequency-domain design objectives. (HW Sets #3 and #4)
3. analyze system stability using Routh-Hurwitz approach. (HW Set #5)
4. use root locus (HW Set #6), Nyquist, and Bode (HW Set #8) techniques to design PID (HW Set #7) and lead/lag (HW Set #9) controllers; analyze resulting closed-loop systems.

ABET CONTENT CATEGORY: 100% Engineering (Design component).
**COURSE TITLE:** ECE 361 Computer Architecture-I

**CATALOG DESCRIPTION:** Design and understanding of the computer system as a whole unit. Performance Evaluation and its role in computer system design; Instruction Set Architecture design, Datapath design and optimizations (e.g., ALU); Control design; Single cycle, multiple cycle and pipeline implementations of processor; Hazard detection and forwarding; memory hierarchy design; Cache memories, Virtual memory, peripheral devices and I/O.

**REQUIRED TEXTS:**

1. Class notes (copies of lecture transparencies) handed out to students.

**COURSE COORDINATORS:** Alok Choudhary

**COURSE GOALS:**

To teach designing a complete computer system. Includes designing instruction set architecture, datapaths, control, memory hierarchy including cache memories, virtual memory and I/O systems.

**PREREQUISITES:** ECE 205 and 303

**PREREQUISITES BY TOPIC:**

1. Basic logic design
2. Understanding adders, multipliers and dividers
3. Assembly language

**DETAILED COURSE TOPICS:**

**Week 1:** Introduction: Components of a computer system. Evolution of Technology. Factors affecting computer systems design (e.g., technology, applications, performance requirements). READING: Chapter 1.


**Week 3:** Instruction Set Architecture design. The role of an instruction set, interface between hardware and software; issues to consider when designing an instruction set; addressing modes. READING: Chapter 3.
**Week 4:** Arithmetic and Logic Units (ALU) for computers. Number system, addition and subtract, adders; multiplication and multipliers; division and dividers; floating point numbers and floating point units; Examples from existing systems. READING: Chapter 4.

**Week 5:** Processor Design. Datapath and control; single cycle design and implementation; simplifying control design; multicycle implementation of datapath and control; example from a real system. READING: Chapter 5.

**Week 6:** Pipelining. Basic concepts in pipelining; datapath for pipeline processor implementation, data hazard and forwarding, data hazard and stalling; control design for pipelines, superscaler design; Examples. READING: Chapter 6.

**Week 7:** Memory Hierarchy: Cache memories. Introduction to caches, measuring and improving performance of caches; design alternatives, direct map, associative caches; replacement policies; examples. READING Chapter 7.

**Week 8:** Virtual Memory: basic design, address translation, placement and replacement; cost and performance issues; common framework for memory hierarchies, Translation Lookaside Buffers. READING Chapter 7.

**Week 9:** Input-Output and Peripheral Devices. I/O performance and measures, technology and characteristics of disks. Busses and protocols. Connecting I/O devices to memory and processor. READING Chapter 8.

**Week 10:** I/O systems design. RAIDs. Memory bandwidth and bus bandwidth requirements for graphics. Example of a typical I/O system. Introduction to multiprocessors. Summary/ READING: Chapter 8 and 9.

**COMPUTER USAGE:** Students use Mentor Graphics design tool to implement a simple single cycle processor with limited instruction set. Use processor simulators to learn and evaluate working of processors. Cache simulators to evaluate cache memory performance.

**PROJECT:** A quarter long project that entails designing a single cycle processor using mentor graphics tool and its evaluation using simple programs. Each week students submit progress on additions to the design.

**GRADES:**
Five homeworks - 20%
Project - 30%
Midterm exam - 20%
Final exam - 30%

**COURSE OBJECTIVES:** When a student completes this course, s/he should be able to:

1. Understand the architecture of a basic computer system and its components, and the role of performance in designing computer systems.
2. Understand how to design and instruction set and its impact on processor design. To design ALU and processor datapath and control.
3. Design pipeline processor including datapath and control, and design to detect and resolve hazards.
4. Understand memory hierarchy design and its impact on overall processor performance. Design cache memory based on the characteristics of the expected workload. Understand the workings of virtual memory and efficient design for TLBs
5. Understand the I/O system and its design. Be Knowledgeable about Busses and bandwidth requirements to support heterogeneous I/O devices. Understand the disk technology and its impact on performance.

**ABET CONTENT CATEGORY:** 100% Engineering (Design component).
**COURSE TITLE:** ECE 362 Computer Architecture Project

**CATALOG DESCRIPTION:** Quarter long team project that entails designing a processor for a complete Instruction Set. Involves ISA design, design of components, datapath and control for a pipelined processor to implement the ISA. The design is performed using industry strength design tools and VHDL is used as the design specification language. The design is evaluated using benchmark programs for correctness and performance.

**REQUIRED TEXTS:**

**REFERENCE TEXTS:**

**COURSE COORDINATORS:** Alok Choudhary

**COURSE GOALS:** To learn designing and implementing processor architecture and learn to work in design teams. To understand the design process based on requirements and then implementing and evaluating the design using tools.

**PREREQUISITES:** ECE 361

**PREREQUISITES BY TOPIC:**
1. Instruction Set Architecture
2. Understanding adders, multipliers and dividers
3. Datapath, Control, Pipelining

**DETAILED COURSE TOPICS:**

**Week 1:** Form teams. Understand project. Learn instruction set for which processor will be designed.

**Week 2:** Each team presents a "first" plan for the processor design, validation and evaluation. Begin to assign OPCODES to ISA.

**Week 3:** Present a refined plan of processor. Start implementing components for ALU and control using design tools and VHDL.

**Week 4:** Present the progress in previous week and describe how the problems faced during last week were solved. Describe progress on component implementation. Present plan for component integration.

**Week 5:** Present the progress in previous week and describe how the problems faced during last week were solved. Describe progress on component implementation. Present the final design of the processor including control. Midterm presentations on the design.

**Week 6:** Present the progress in previous week and describe how the problems faced during last week were solved. Describe progress on component implementation. Demonstrate progress on
integration of components. Present the testing of components and overall test and evaluation plan. Adapt application codes to be evaluated.

**Week 7:** Present the progress in previous week and describe how the problems faced during last week were solved. Describe progress on integration. Demonstrate the current design for initial evaluation.

**Week 8:** Present the progress in previous week and describe how the problems faced during last week were solved. Demonstrate simple programs running against the processor simulator (written in VHDL).

**Week 9:** Present the progress in previous week and describe how the problems faced during last week were solved. Demonstrate bug fixes and performance enhancements.

**Week 10:** Present the progress in previous week and describe how the problems faced during last week were solved. Demonstrate the final design against benchmark programs, Present the overall design report.

**COMPUTER USAGE:** Students use Mentor Graphics design tools and VHDL to implement a pipelined processor.

**PROJECT:** The class is a quarter long team project to design a pipelined processor.

**GRADES:**
Homeworks/Weekly Presentations - 25 %
Project-Final Design - 75 %

**COURSE OBJECTIVES:** When a student completes this course, s/he should be able to:

1. Understand the design process for computers and learn how to work in teams to achieve the goals of the project.

2. Understand the architecture of a basic computer system and its components, and the role of performance in designing computer systems.

3. Understand how to design and instruction set and its impact on processor design. To design ALU and processor datapath and control. Design pipeline processor including datapath and control, and design to detect and resolve hazards.

4. Understand how to use CAD tools to design a processor.

**ABET CONTENT CATEGORY:** 100% Engineering (Design component).
COURSE TITLE: ECE 363 Digital Filtering

CATALOG DESCRIPTION: Recursive and nonrecursive digital filters, decimation and interpolation, A/D and D/A conversion as digital filtering problems. Implementation of nonrecursive filters via FFT, quantization problems, e.g., companding and limit cycles.

REQUIRED TEXTS: none


COURSE COORDINATOR: Arthur R. Butz

COURSE GOALS: Study parameters, structures and problems of digital filters. Computer-aided frequency domain design of digital filters using contemporary standard software.

PREREQUISITES: ECE 359

PREREQUISITES BY TOPIC:
1. Fundamentals of signals and linear systems; Fourier and Laplace transforms.
2. The z-transform.
3. Discrete Fourier Transform.

DETAILED COURSE TOPICS
3. Filter banks.
5. A/D and D/A conversion as filtering problems.
6. Finite word length effects.

COMPUTER USAGE: MATLAB, including the signal processing toolbox, is used on a platform of the student's choice, to carry out the determination and study of digital filters.

LABORATORY PROJECTS: See Computer Usage.

GRADES:
Labs - 25%
Midterm - 25%
Final - 50%
COURSE OBJECTIVES: When a student completes this course, s/he should be able to:
1. Construct frequency domain specifications for digital filters.
2. Use computer software to determine digital filters meeting frequency domain specifications, in either the FIR or IIR forms, when applicable.
3. Determine structures that implement digital filters.
4. Determine word length requirements in specific problems.

ABET CONTENT CATEGORY: 100% Engineering (Design component).
COURSE TITLE: ECE 379 Introduction to Lasers and Fiber Optics

CATALOG DESCRIPTION: Optical fields as a subset of electromagnetic fields, optical cavities, theory of laser action, and the basics of optical waveguides, including optical fiber.

REQUIRED TEXT: B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics, John Wiley & Sons, 1991 $115
F. Graham Smith and Terry A. King, Optics and Photonics, John Wiley & Sons, 2000, $51 paperback

REFERENCE TEXTS:

COURSE COORDINATOR: Mary R. Phillips

COURSE GOALS: To introduce optics, lasers and optical waveguides. After taking this class, a student should understand the basics of optical fields including polarization, coherence, and behavior at dielectric interfaces. He or she should also understand the fundamentals of optical amplification, lasers, and optical waveguides.

PREREQUISITES: ECE 222 and ECE 224

COURSE TOPICS:

1. Review of electromagnetic fields and waves.
2. Optical waves at dielectric boundaries: reflection and transmission
3. Gaussian Beams
4. Optical coatings for high or low reflectivity
5. Interference and optical resonators
6. Fundamentals of lasers
7. Dielectric waveguides, including optical fiber
8. Transmission effects of optical waveguides: loss and dispersion

COMPUTER USAGE: Use of MATLAB, EXCEL or other spreadsheet software.

HOMEWORK ASSIGNMENTS:
These will reinforce the concepts introduced in lecture.

LABORATORY: There will be approximately five hands-on laboratory projects.

BASIS for GRADE: Homework, laboratory write-ups, one midterm test, and final exam.
COURSE OBJECTIVES: When a student completes this course, he or she should be able to:

1. Understand the basic properties of optical fields
2. Understand the fundamental principles of optical amplification and lasers
3. Understand and design basic optical dielectric waveguides
4. Take more advanced courses in fiber optic communication and optical signal processing.

ABET CONTENT CATEGORY: 100% Engineering (Design Component)
COURSE TITLE: ECE 380 Wireless Communications

CATALOG DESCRIPTION: Overview of existing and emerging wireless communications systems; interference, blocking, and spectral efficiency; radio propagation and fading models; performance of digital modulation in the presence of fading; diversity techniques; Code-Division Multiple Access.


COURSE DIRECTOR: Michael Honig

COURSE GOALS: To teach the principles underlying the design of digital wireless communications systems, namely, cellular systems, the effect of radio propagation on digital communications systems, methods for improving reliability, and multiple access techniques.

PREREQUISITES BY COURSES: 378

PREREQUISITES BY TOPIC:
1: Probability and random variables
2: Autocorrelation and power spectral density.
3: Familiarity with digital modulation techniques such as BPSK and QPSK.

DETAILED COURSE TOPICS:
Week 1: Overview of current and emerging wireless systems, including cellular, PCS, and third generation systems; cellular models and frequency reuse.
(READINGS: Rappaport, Chapters 1 and 2)
Week 2: Narrowband cellular, interference and system capacity, sectorization, cell splitting, spectral efficiency, trunking and grade of service. (READINGS: Rappaport, Ch. 3)
Week 3: Handoff and outage probability, introduction to radio propagation: large- and small-scale effects, multipath, path loss, log-normal shadowing, empirical path loss models.
(READINGS: Rappaport, Secs. 4.1, 4.2, 4.9, 4.10 (up to 4.10.5))
Week 4: Review of complex baseband model, linear time-varying channels, narrowband signals and Rayleigh fading, Ricean fading, Doppler shift, Doppler spread with uniform scattering.
(READINGS: Rappaport, Secs. 5.1, 5.2, 5.6, 5.7)
Week 5: Fade statistics, coherence time, fast vs. slow fading, broadband signals and power delay profile, coherence bandwidth, flat vs. frequency-selective fading, effect on digital transmission.
(READINGS: Rappaport, Secs. 5.4, 5.5)
Week 6: Review of digital and quadrature modulation, error probability with additive Gaussian noise and flat Rayleigh fading, coherent and noncoherent (differential) detection.
(READINGS: Rappaport, 6.4, 6.5, 6.6, 6.7, 6.8 excluding 6.8.5, 6.12 excluding 6.12.2-3)
Week 7: Frequency-Shift Keying, coherent and noncoherent demodulation, Minimum-Shift Keying, Gaussian MSK, power and bandwidth efficiencies. Overview of diversity techniques.
(READINGS: Rappaport, Secs. 6.9, 7.10 excluding 7.10.4, 7.11)
Week 8: Diversity combining techniques: selection, max-ratio, equal-gain. Overview of error control coding techniques, interleaving.
(READINGS: Rappaport, Secs. 7.12, 7.13, 7.14 excluding 7.14.2, 7.15-7.18 excluding 7.15.1)

Week 9: Frequency- and Time-Division Multiple Access, arrangement of channels for AMPS, frame structure for IS-136 and GSM standards, capacity. Direct-Sequence Code-Division Multiple Access.
(READINGS: Rappaport, Secs. 9.1-9.4, 11.1, 11.2, 11.3 excluding 11.3.7)

(READINGS: Rappaport, Secs. 6.11 excluding 6.11.5, 9.7.1, 11.4 up to 11.4.2)

HOMEWORK ASSIGNMENTS:
Homework 1: Problems on classification and general properties of wireless systems, computation of signal-to-interference ratio, capacity, and spectral efficiency with and without sectorization.

Homework 2: Problems on path loss and effect of log-normal shadowing, computation of delay spread, and computation of fade statistics and Doppler spectrum.

Homework 3: Problems on computation of error rate for digital modulation with and without fading, performance of noncoherent detection, and specification of GMSK waveform.

Homework 4: Problems on the performance of diversity combining techniques.

Homework 5: Problems on the performance of Direct-Sequence Code-Division Multiple Access.

COMPUTER PROJECTS: Matlab assignments include generation of a scatter plot of received powers with large-scale path loss and shadowing, generation of a Rayleigh fading process, and simulation of a simple digital communications model with Rayleigh fading and diversity.

LABORATORY PROJECTS: None.

GRADES:
Four homeworks (including computer assignments): 20%
Midterm: 30%
Final: 50%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Classify many of the current and emerging (next generation) wireless information networks.
2. Characterize the tradeoffs among frequency reuse, signal-to-interference ratio, capacity, and spectral efficiency.
3. Apply exponential path loss models with log-normal shadowing to determine received power.
4. Characterize small-scale variations in terms of Doppler spectrum, coherence time, power delay profile, and coherence bandwidth.

5. Characterize performance (error probability) for coherent modulation with and without flat Rayleigh fading, specify FSK, MSK, and GMSK waveforms and describe associated spectral properties.


7. Identify commonly used forms of diversity and evaluate the performance of selection and max-ratio combining in flat Rayleigh fading.

8. Characterize Time- and Frequency-Division Multiple Access, and evaluate the associated system capacity and efficiency.

9. Characterize Direct-Sequence Code-Division Multiple Access, and compute the associated Signal-to-Interference Plus Noise Ratio and system capacity for simple channel and receiver models.

**ABET CONTENT CATEGORY:** 100% Engineering (Design component).
COURSE TITLE: ECE 381 Electronic Properties of Materials

CATALOG DESCRIPTION: Quantum physics; electrons and energy bands in crystals; electronic transport in materials, superconductivity; optical properties of materials and their applications; magnetic properties of materials and their applications; thermal properties of materials.


COURSE COORDINATOR: Manijeh Razeghi

COURSE GOALS: The course is designed to provide the opportunity for students from different backgrounds to undertake study and research in solid state engineering and electronic materials. For those students who look toward an industrial position after graduation, this course is designed to widen background in material engineering and help them to meet the industry demand. For students who plan on graduate studies, it provides an excellent opportunity to prepare themselves for advanced study in a variety of different areas of solid state engineering and material science: metals, semiconductors, superconductors, optical, magnetic and amorphous materials. The course is meant to create the background needed to understand the physics of device operations and also prepare students for advanced courses in solid state and quantum electronics.

PREREQUISITES BY COURSES: ECE 223 or consent of Instructor.

DETAILED COURSE TOPICS:

WEEK 1: Electrons and energy bands in crystals: one-dimensional zone schemes, Brillouin zones, reciprocal lattice, free electron band structures of metals and semiconductors, Fermi energy, Fermi surface, Fermi distribution, density of states, effective mass.

WEEK 2: Electrical conduction in metals and alloys: classical electron theory and quantum mechanical treatment of conductivity, experimental results, superconductivity.

WEEK 3: Electrical conduction in polymers, ceramics, and amorphous materials: conducting polymers and organic metals, ionic conduction, conduction in metal oxides, amorphous materials.

WEEK 4: Optical properties of materials: optical constants, index of refraction, damping constant, penetration depth, absorbance, reflectivity, transmissivity, Hagen-Rubens relation; atomistic theory, free electrons, bound electrons, harmonic oscillators.

WEEK 5: Quantum mechanical treatment of the optical properties: absorption, interband and intraband transitions, optical spectra of materials.

WEEK 6: Applications of the optical properties of materials: Kramers-Kronig analysis, reflection spectra, semiconductors, insulators, gas lasers, semiconductor lasers, light-emitting
diodes, integrated optoelectronics, waveguides, modulators, switches, optical data storage, optical computer.

**WEEK 7:** Magnetic phenomena and their classical interpretation: basic concepts, diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism, ferrimagnetism, Langevin theory.

**WEEK 8:** Quantum mechanical considerations of the properties of materials and their applications: paramagnetism, diamagnetism, ferromagnetism, antiferromagnetism, soft and hard magnetic materials, permanent magnets, magnetic recordings, magnetic memories.

**WEEK 9:** Fundamentals of thermal properties of materials: heat, work, energy, heat capacity, thermal conductivity, ideal gas theory, kinetic theory of gases.

**WEEK 10:** Advanced thermal properties of materials: classical and quantum mechanical theory of heat capacity, Einstein and Debye models, phonons, classical and quantum mechanical considerations of thermal conduction in metals and alloys, thermal conduction in dielectric materials, thermal expansion.

**COMPUTER USAGE:** None

**LABORATORY PROJECTS:**
1. Measurement of electron charge
2. Hall effect
3. Thermoelectric effect
4. Electrical properties of point contacts
5. Ferromagnetic phase transition
6. Demonstration of superconductivity
7. Photoconductivity
8. Light-emitting diode

**GRADES:**
Homework - 25%, Labs - 25%, Midterm - 25%, Final - 25%

**COURSE OBJECTIVES: When a student completes this course, s/he should be able to:**
1. Understand the quantum mechanics of electron in crystals.
2. Understand the basic electrical and magnetic properties of crystalline solids and amorphous materials.
3. Understand the difference between electronic structures and physical properties of semiconductors, metals, and dielectrics.
4. Understand the physics of magnetic phase transitions and superconductivity.
5. Measure and analyze transport characteristics of semiconductors.
6. Measure and analyze basic optical parameters of semiconductors.
7. Understand the physics behind solid state electronics and optoelectronic devices.
8. Understand the basic design of major microelectronic and optoelectronic devices, their features, and limitations.
9. Present the results of study and research.

**ABET:** 90 % Science, 10 % Engineering
COURSE TITLE: ECE 382 Photonic Information Processing

CATALOG DESCRIPTION: Introduction to photonic information processing; coherent and incoherent light; electro-optic and acousto-optic modulation; optical signal processing; holography; optical storage.

REQUIRED TEXT: Saleh and Teich, Fundamentals of Photonics, Wiley, Latest Edition. In addition, course notes will be distributed.


COURSE COORDINATOR: Prem Kumar

COURSE GOALS: Introduce students to concepts in photonic information processing, i.e., how light is used in modern systems for encoding, manipulating, storing, and retrieving information.

PREREQUISITES: ECE 308 and ECE 379.

DETAILED COURSE TOPICS:

Week 1: Introduction to Photonic Information Processing, Coherent vs. Incoherent Light

Week 2: Optical Propagation—a Linear System Approach: Paraxial Approximation and Fresnel Diffraction

Week 3: Gaussian Beams of Light and Their Propagation Characteristics

Week 4: Far-Field Limit and Fraunhofer Diffraction

Week 5: Thin Lens Imaging and Resolution Limits

Week 6: Optics of Anisotropic Media, Electro-optic Effect

Week 7: Propagation in Anisotropic Media, Electro-optic Modulation

Week 8: Acousto-optic Effect, Interaction of Light and Sound, AO Modulation

Week 9: Spatial Light Modulation, Application to Photonic Signal Processing

Week 10: Holography and Optical Storage

COMPUTER USAGE: Incidental use of MATLAB, Mathematica, or equivalent.

HOMEWORK ASSIGNMENTS: Homework assignments will be given to reinforce concepts taught in class.
LABORATORY PROJECTS: A few lab demonstrations of examples of photonic information processing will be presented.

GRADES: Homeworks – 20%, Exams – 80%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Have an understanding of photonic information processing.
2. Know what is the difference between coherent and incoherent light.
3. Understand how coherent light propagates in free space—that free-space propagation is equivalent to a linear shift-invariant filter.
4. Understand the differences between plane waves and Gaussian beams of light, the latter being the outputs of most lasers.
5. Do detailed calculations relating to the propagation and focusing of Gaussian beams of light.
6. Know how free-space diffraction affects the design of satellite-to-satellite and other open-space optical communication links.
7. Understand imaging with thin lenses and the origin of the fundamental resolution limit.
8. Know how light propagates in anisotropic media and what are electro-optic and acousto-optic effects.
9. Understand basic concepts of electro-optic and acousto-optic modulation of light.
10. Know how the above concepts are used in photonic information processing.
11. Apply the theory of light propagation to understand how holography and optical storage works.
12. Be prepared to take advanced courses in the area of photonics.

ABET CONTENT CATEGORY: 100% Engineering (Design component).
COURSE TITLE: ECE 383 Fiber-Optic Communications

CATALOG DESCRIPTION: Introduction to fiber-optic communications. Semiconductor diode lasers, internal modulation, electro-optic modulation, coherent and incoherent detection, optical fibers and their properties, optical amplifiers, communication systems, and optical networks.


COURSE COORDINATOR: Mary R. Phillips

COURSE GOALS: To introduce students to the field of fiber-optic communication. Topics to be covered include semiconductor diode lasers, internal modulation, electro-optic modulation, optical fibers and their properties, optical amplifiers, communication systems, and optical networks.

PREREQUISITES: ECE 308 or ECE 379

DETAILED COURSE TOPICS:

- Optical Fibers and their Properties
- Optical Transmitters
  - Semiconductor Diode Lasers
  - Internal Modulation
  - Electro-optic Modulation
- Optical Amplifiers
- Optical Receivers
- Communication Systems
- Advanced Topics (one of the following)
  - Coherent and Incoherent Detection
  - Multichannel Lightwave Systems (WDM or TDM)
  - Dispersion Compensation
  - Soliton Communication Systems

COMPUTER USAGE: Incidental use of MATLAB, Mathematica, or equivalent.

HOMEWORK ASSIGNMENTS: Homework will reinforce concepts learned in class.

GRADES: Homework, one midterm test, and final exam.

COURSE OBJECTIVES: When a student completes this course, he or she should be able to:

1. Understand the functionality of each of the components that comprise a fiber-optic communication system: transmitter, fiber, amplifier, and receiver.
2. Understand the properties of optical fiber that affect the performance of a communication link.
3. Understand how semiconductor lasers work, and differentiate between direct modulation and external electro-optic modulation.
4. Understand basic optical amplifier operation and its effect on signal power and noise in the system.
5. Apply concepts listed above to the design of a basic communication link.

**ABET CONTENT CATEGORY:** 100% Engineering (Design component).
**COURSE TITLE:** ECE 386 Computational Electromagnetics and Photonics

**CATALOG DESCRIPTION:** Introduction to the finite-difference time-domain (FDTD) method in numerical modeling of electromagnetic and optical wave interactions with engineering structures. Topics: finite differences; Maxwell’s equations; numerical dispersion and stability; free-space and waveguide field sources; absorbing boundary conditions; material dispersions and nonlinearities.


**COURSE COORDINATOR:** Allen Taflove

**COURSE GOALS:** To provide the electrical engineering student with the foundation to numerically model electromagnetic wave interactions in modern electronic and optical circuits.

**PREREQUISITE:** ECE 308 or the equivalent.

**DETAILED COURSE TOPICS:**

<table>
<thead>
<tr>
<th>Week</th>
<th>Lectures</th>
<th>Topic</th>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Introduction to contemporary problems in electromagnetic wave engineering and techniques in computational electromagnetics.</td>
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<tr>
<td></td>
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<td>Development of finite differences from Taylor series; truncation error.</td>
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<td></td>
<td>Application of finite differences to the 1-D scalar wave equation.</td>
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<td></td>
<td><strong>Assign Project 1:</strong> Simulate the 1-D time-domain scalar wave equation; investigate its numerical dispersion, stability, and accuracy properties.</td>
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<td>2</td>
<td>4</td>
<td>Numerical dispersion of the 1-D scalar wave equation.</td>
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<td>5</td>
<td>Numerical stability of the 1-D scalar wave equation.</td>
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<td>6</td>
<td>Simple 1-D wave source and absorbing boundary conditions.</td>
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<td>3</td>
<td>7</td>
<td>Review of Maxwell’s equations in differential and integral form; transverse electric (TE) and transverse magnetic (TM) polarizations.</td>
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<td>8</td>
<td>Introduction to Yee’s central differencing in 1-D space and time.</td>
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<td>9</td>
<td>Numerical dispersion of the 1-D Yee algorithm.</td>
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<td><strong>Assign Project 2:</strong> Program the 1-D Yee algorithm with wave-source and absorbing boundary conditions; examine its numerical dispersion, stability, and accuracy properties.</td>
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<td>4</td>
<td>10</td>
<td>Numerical stability of the 1-D Yee algorithm.</td>
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<td>11</td>
<td>Simple wave sources and absorbing boundaries for the Yee grid in 1-D.</td>
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<td>12</td>
<td>Total-field / scattered-field zoning for the Yee grid in 1-D.</td>
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<td>Section</td>
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<tr>
<td>5</td>
<td>Introduction to Yee’s central differencing in 2-D space and time.</td>
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<td></td>
<td>Numerical dispersion of the 2-D Yee algorithm.</td>
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<td></td>
<td>Numerical stability of the 2-D Yee algorithm.</td>
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<td><strong>Assign Project 3</strong>: Program the 2-D TM Yee algorithm to model the</td>
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<td>propagation of a cylindrical wave radiated by a line source.</td>
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<td>Examine the numerical dispersion and stability properties of the</td>
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<td>algorithm.</td>
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<td>6</td>
<td>Theory of analytical absorbing boundary conditions (ABC’s) in 2-D.</td>
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<td>Theory of 2-D analytical ABC’s, continued.</td>
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<td>Theory and numerical implementation of the Liao ABC.</td>
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<td>7</td>
<td>Introduction to Berenger’s perfectly matched layer (PML) ABC.</td>
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<td>Berenger’s PML ABC, continued.</td>
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<td>Introduction to the uniaxial PML (UPML) ABC.</td>
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<td><strong>Assign Project 4</strong>: Incorporate the third-order Liao ABC in the</td>
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<td>grid of Project 3. Demonstrate outer-boundary reflectivity in the</td>
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<td>order of 1% or lower for an outgoing cylindrical wave.</td>
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<td>8</td>
<td>Propagation in metal-wall waveguides; cutoff and dispersion phenomena.</td>
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<td>Propagation in dielectric slab waveguides; cutoff and dispersion</td>
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<td>phenomena.</td>
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<td>Introduction to propagation in defect-mode photonic crystals.</td>
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<td>9</td>
<td>Introduction to the macroscopic physics of dispersive materials.</td>
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<td>Auxiliary differential equation (ADE) modeling of dispersive</td>
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<td>materials.</td>
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<td>ADE modeling of dispersive materials, continued.</td>
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<td><strong>Assign Project 5</strong>: Use the grid of Project 4 to model a parallel-</td>
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<td>plate metal waveguide and a dielectric slab waveguide. Demonstrate</td>
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<td>cutoff and propagation phenomena for the lowest-order even and odd</td>
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<td>modes for each type of waveguide.</td>
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<tr>
<td>10</td>
<td>Nonlinear materials; formation of temporal and spatial optical</td>
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<td>solitons.</td>
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<td>Incorporation of optical gain; 1-D microcavity laser simulations.</td>
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<td>Recent developments and research horizons.</td>
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</table>

**COMPUTER USAGE:** Five programming project assignments (see above).

**LABORATORY:** None

**GRADES:** No exams. Instead each student is assigned five electromagnetic wave simulation projects of progressive difficulty and sophistication weighted at 10%, 15%, 20%, 25%, and 30% of the final grade. Each project requires: (1) solution of the associated homework problems that spotlight the fundamental underlying theory; and (2) development of simulation software from
the fundamental theory using Matlab, Fortran, C, or C++ as selected by each student. Grading factors include assessment of student understanding of the theory, success in programming, and effectiveness in displaying the results of the simulations.

**COURSE OBJECTIVES: When a student completes this course, s/he should be able to:**

1) Understand the scope of contemporary and emerging application areas in electromagnetic wave technology, especially high-speed electronic and optical communications.

2) Understand the concepts and analysis approaches for numerical dispersion and stability of FDTD electromagnetic wave simulations.

3) Understand means to source waves in free space and in waveguides in numerical FDTD simulations.

4) Understand the theory and numerical implementation of widely used analytical and PML absorbing boundary conditions for FDTD grids.

5) Understand the mathematical basis and numerical modeling of frequency-dispersive and nonlinear materials in FDTD simulations.

6) Construct working software that implements FDTD codes capable of solving real electromagnetic wave and optical engineering problems.

7) Begin to read the research literature in FDTD modeling for engineering electromagnetics.

**ABET CONTENT CATEGORY:** 100% Engineering (Design component)
COURSE TITLE: ECE 388 Microelectronic Technology


REFERENCE TEXTS:
1. M. Razeghi, *MOCVD Challenge Vol. 1*
2. M. Razeghi, *MOCVD Challenge Vol. 2*

COURSE COORDINATOR: Manijeh Razeghi

COURSE GOALS: Nanotechnology: The course is designed to teach the elements of advanced science and technology used in nanotechnology materials and nanodevice fabrication. The topics taught include the fundamentals of: quantum mechanics, nanoscale quantum structures, bulk semiconductor and epitaxial growth techniques, vacuum technology, diffusion and implantation, wafer manufacturing, and processing.

PREREQUISITES: ECE 223 or consent of instructor.

DETAILED COURSE TOPICS:

WEEK 1: Review of concepts in quantum mechanics (limits of classical mechanics, basic concepts of quantum mechanics, quantization of electromagnetic field, photon, wave-particle duality, wave function, probability of presence, Schrödinger equation, quantization of energy levels and momenta, tunneling, infinite potential well, finite potential well).

Review of electrons and energy band structures in crystals (Bloch theorem, Kronig-Penney model, energy bands, nearly-free electron approximation, tight binding approximation, Heisenberg uncertainty principle, Fermi energy, Fermi distribution, holes, first Brillouin zone, band structures in metals).

WEEK 2: Compound semiconductors and crystal growth techniques (1/2): III-V semiconductor alloys, bulk single crystal growth techniques (Czochralski, Bridgman, float zone).

WEEK 3: Compound semiconductors and crystal growth techniques (2/2): liquid phase epitaxy, vapor phase epitaxy, metalorganic chemical vapor deposition, molecular beam epitaxy.


WEEK 5: Semiconductor device nanotechnology (2/2): ion implantation, characterization of sheet resistivity and junction depth.

WEEK 6: Semiconductor nanodevice processing: photolithography, electron beam lithography, etching, metallization, packaging of nanodevices.

WEEK 7: Semiconductor lasers: general laser theory, stimulated emission, resonant cavity,
waveguides, beam divergence, ruby laser, population inversion, threshold condition, output power, homojunction and heterojunction lasers, separate confinement, quantum well lasers, quantum cascade lasers, type II lasers, quantum dot and vertical cavity surface emitting lasers.

**WEEK 8:** Photodetectors: electromagnetic radiation, responsivity, noise, detectivity, frequency response, thermal detectors, photon detectors, photovoltaic and photoconductive detectors, avalanche photodiodes, Schottky barrier photodiodes, metal-semiconductor-metal photodiodes, type-II superlattice detectors, quantum well intersubband photodetectors, photoelectromagnetic detectors.

**WEEK 9:** Semiconductor device laboratory demonstration: semiconductor growth technology, device processing technology and device measurement techniques.

**WEEK 10:** Project presentations.

**COMPUTER USAGE:** None.

**HOMEWORK ASSIGNMENTS:** Homework is assigned weekly to reinforce concepts learned in class.

**PROJECTS:** The students will work in group on a project to design, fabricate, and test an optoelectronic circuit, or build a model related to the crystal structure of semiconductors. A written report and an oral presentation will be prepared.

**GRADES:**
- Homework - 25%
- Midterm - 25%
- Project - 25%
- Final - 25%

**COURSE OBJECTIVES:** When a student completes this course, s/he should understand nanotechnology by being able to:

1. Recognize and classify a crystal, recognize its structural properties, including symmetry operations, be knowledgeable in common semiconductor crystal structures.
2. Understand the basic concepts of quantum mechanics and be able to solve basic quantum mechanical problems.
3. Understand the physical meaning of energy band diagrams of semiconductor, the concept of effective masses and Brillouin zones.
4. Be knowledgeable in the various modern technologies used in nanotechnology to grow bulk crystals, thin films, and nanoscale quantum structures, including the epitaxy of semiconductors, understand the advantages and drawbacks of each of the techniques. Be familiar with Vegard's law and the concept of bandgap bowing.
5. Design compound semiconductor laser device structure emitting light at 1.3 \( \mu \text{m} \) and 1.5 \( \mu \text{m} \).
6. Manipulate and calculate physical parameters related to nanotechnology, such as impingement rates, mean free paths and residual partial pressures.
7. Solve simple problems related to thin film deposition techniques (evaporation, sputtering, chemical vapor deposition etc.), such as for example determining the film growth rate
8. Interpret common semiconductor materials characterization data, as published in modern journal articles.
9. Design complete doping processes to achieve p-n junctions at a desired depth using successive diffusion and ion implantation experiments.
10. Design a photolithographic mask, design a sequence of steps in the processing of a semiconductor wafer into a final operational device, involving photolithography, electron beam lithography, etching, metallization and passivation.

**ABET:**
50 % Science, 50 % Engineering
**COURSE TITLE:** ECE 394 ASIC and FPGA Design

**CATALOG DESCRIPTION:** Overview of Computer Aided Design tool flow for ASIC and FPGA Design. Synthesis from hardware description languages and creation of finite state machines. Differences between FPGA and ASIC design flows. Exploration of concepts in several projects.


**REFERENCE TEXTS:** Course handouts

**COURSE DIRECTOR:** Seda Ogrenci Memik

**COURSE GOALS:** To introduce students to the process of designing application specific hardware implementations of algorithms for ASICs and FPGAs. Students will work with commercial computer aided design tools to synthesize designs described in hardware description languages. Topics covered will include differences between hardware description languages for synthesis and simulation, behavioral synthesis, gate-level design, register transfer level design, design methodologies, finite state machines, design reuse and intellectual property cores, and optimization.

**PRE-REQUISITES:** ECE 303 or equivalent.

**DETAILED COURSE TOPICS**

**Week 1:** Overview of VHDL. Introduce synthesis and subset.

**Week 2:** Continue discussion synthesis subset. Review finite state machines.

**Week 3-4:** Introduce ASIC design methodologies and synthesis tools, VHDL simulation and verification

**Week 5:** Discuss standard libraries. Introduce optimizations

**Week 6-7:** Introduce FPGA Synthesis tools and Intellectual Property Cores

**Week 8-10:** Topics TBA, related to main project.

**COMPUTER USAGE:** Students will be expected to be comfortable with Sun/UNIX platform to run and manage Computer Aided Design projects with synthesis tools.

**LABORATORY PROJECTS:** Course is project oriented. Students will gain experience writing hardware designs in VHDL using several different styles (including behavioral, gate level design and Register Transfer Level Design). They will use industry standard computer-aided design tools including tools from Synopsys, Cadence, Synplicity, and Xilinx. They will target commercially viable standard libraries to create physical layout of ASICs and work with industry standard FPGAs from Xilinx. Each student will have the opportunity to design several projects individually and work in groups to create larger designs.
**GRADES:**
Grades will be 100% project based

**COURSE OBJECTIVES:** When a student completes this course, s/he should be able to:

1. Have an understanding of the difference between VHDL code for hardware simulation and hardware synthesis.
2. Understand the basic strategies for hardware design using VHDL.
3. Understand and critically compare state-of-the-art design automation methodologies.
4. Use computer aided design tools to physically synthesize a design written in VHDL and generate a physical layout for testing and fabrication.
5. Use computer aided design tools to synthesize a design written in VHDL and generate a bitstream for execution on an FPGA.
6. Write intelligent VHDL designs that show understanding of basic hardware that will be synthesized with tools.
7. Verify hardware designs at several levels in the design flow.
8. Understand the need for and application of different optimization techniques, and their relative interaction within computer aided design tools.
9. Take advantage of pre-existing intellectual property to reduce design time and produce more optimal results.
COURSE TITLE: ECE 397-2 Formal Techniques in Design and Verification

CATALOG DESCRIPTION: Formal specification, design, and proof techniques for digital systems (hardware or software): propositional and predicate logics; system specifications; correctness proofs; model checking.


COURSE DIRECTOR: Hai Zhou

COURSE GOALS: The biggest challenge in digital system design is to maintain the complexity at a manageable level. Considering the behavior of a system case by case is no longer working, either in design or verification. Formal techniques treat a design as a mathematical object and establish its behavior from its structure through mathematical reasoning--that is, proofs. In this course, we will study a selected set of formal techniques and their applications in digital system specification, design, and verification.

PREREQUISITES BY COURSES: ECE303

DETAILED COURSE TOPICS:

- Week 1: Propositional and predicate logics, sets
- Week 2: State transition systems, simple TLA specifications
- Week 3: Asynchronous interface specification and TLATeX typesetter
- Week 4: Caching memory specifications
- Week 5: Temporal logic: safety and liveness
- Week 6-7: Model checking and TLC
- Week 8: Specification of real time systems
- Week 9-10: Composing and decomposing specifications

COMPUTER USAGE: Specification projects will be done with TLATeX typesetter and TLC model checker on computers.

LABORATORY: Accounts can be arranged for ECE Department Workstation Lab. Students can also install the tools on their own computers.

GRADES: Homework – 50% Projects – 50%

ABET CONTENT CATEGORY: 100% Engineering (Design component)
COURSE TITLE: ECE 403 Quantum Semiconductors

CATALOG DESCRIPTION: Elements of wave mechanics necessary to explain band theory. Fermi-Dirac statistics, introduction to the theory of electrical conductivity in semiconductors, optical and thermal properties, diffusion of electrons, and holes in solids.


COURSE DIRECTOR: Manijeh Razeghi

COURSE GOALS: The course is designed to provide the understanding of the physics of contemporary quantum electronic devices where quantum confinement plays an important role, and also prepare students for advanced study and research in the variety of different branches of semiconductor quantum electronics. Content includes physics of bulk semiconductors, quantum wells, and superlattices, and covers the basic electrical, optical, and transport phenomena in low-dimensional semiconductor structures.

PREREQUISITES BY COURSES: ECE 381, any solid state physics course, or consent of instructor.

DETAILED COURSE TOPICS:
Week 2: k-p perturbation theory; 8x8 Kane Hamiltonian for III-V materials; effective mass tensor; band non-parabolicity.
Week 4: Coupled-well structures. Kronig-Penney model for a superlattice.
Week 6: Coulomb impurities in bulk materials and quantum wells. Excitons in bulk materials and quantum wells. Interface defects.
Week 10: Resonant tunneling and vertical transport.

GRADES:
Homework- 25%
Exams- 50%
Projects- 25%

**COURSE OBJECTIVES:** When a student completes this course s/he will understand the quantum mechanics of the low-dimensional semiconductor structures: quantum wells, superlattices, quantum dots, quantum wires, understand transport and optical phenomena in these structures, be familiar with methods available for engineering their optical and electrical properties, know area of applications in advanced electronics and optoelectronics.

**ABET:** 100 % Science
COURSE TITLE: ECE 404 Quantum Electronics


REFERENCE TEXTS: None.

COURSE DIRECTOR: Prem Kumar

COURSE GOALS: To review the basic principles of quantum mechanics, and study specific applications, with particular emphasis on topics of interest to graduate students in electrical engineering. Topics include: axioms of quantum mechanics; operators; wavefunction; Schrodinger equation; the hydrogen atom; the harmonic oscillator, creation and annihilation operators; matrix formulation; perturbation theory; lattice vibrations and phonons; electromagnetic fields and their quantization, photons; interaction of radiation and atomic systems; spontaneous and induced transitions; Einstein coefficients; photon statistics.

PREREQUISITES BY TOPIC: Graduate standing in Electrical and Computer Engineering.

DETAILED COURSE TOPICS:

Week 1: Review of Quantum Mechanics
Week 2-3: Hydrogen atom; harmonic oscillator, coherent states
Week 4: WKB approximation and “Old Q. M.”
Week 5: Matrix formulation; perturbation theory; Fermi’s Golden Rule
Week 6: Lattice vibrations and their quantization; phonons
Week 7: Electromagnetic fields and their quantization: Slater modes; second quantization; photons
Week 8: Optical beams in lenslike media: Ray tracing; equation for quasi-plane waves
Week 9-10 Interaction of radiation and atomic systems: atomic susceptibility; atomic transitions; Einstein coefficients

COMPUTER USAGE: Use of Matlab, Mathematica, or equivalent.

GRADES:

Homework – 30%
Midterm exam – 30%
Final exam – 40%
COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Understand basic concepts of quantum mechanics, such as wave functions, uncertainty principle, etc., and their applicability to the description of electrical charges and electromagnetic fields.
2. Perform calculations of energy levels and wavefunctions for standard potential wells. In particular, become familiar with the properties of the harmonic oscillator, including creation and annihilation operators.
3. Understand the principles of the “Old Quantum Mechanics,” and be able to use the WKB method to gain considerable insight into the form of the wavefunctions in arbitrary potential wells.
4. Understand the origin of the matrix formulation of Q.M., and how it relates to the operator formulation.
5. Understand how perturbation theory can be used to calculate interaction strengths; understand in particular the origin and significance of Fermi’s Golden Rule.
6. Understand the dynamics of lattice vibrations from a classical standpoint; be able to make the transition to the Q.M. description, and their quantization. Understand the concept of phonons and their properties.
7. Understand the classical modes of resonance of the electromagnetic field, and make the transition to the Q.M. description, and their quantization. Understand the concept of photons and their properties.
8. Understand the parallel between propagation of light rays in graded index media, and the Schrodinger equation for a particle in a potential well.
9. Understand the Q.M. treatment of the interaction between the electromagnetic field and an atom, and the origin of spontaneous and stimulated transitions; understand the Q.M. calculation of the Einstein coefficients, and its agreement with the semi-classical result.
10. Understand how the density matrix formalism can be used to study photon statistics, and how Gaussian or Poisson statistics are obtained under different circumstances.
COURSE TITLE: ECE 406 Nonlinear Optics

CATALOG DESCRIPTION: Nonlinear optical susceptibilities; wave propagation and coupling in nonlinear media; harmonic, sum, and difference frequency generation; parametric amplification and oscillation; phase-conjugation via four-wave mixing; self-phase modulation and solitons.


REFERENCE TEXTS:

COURSE DIRECTOR: Mary R. Phillips

COURSE GOALS: To give students a working knowledge of the fundamental concepts and modern applications of nonlinear optics.

PREREQUISITES BY COURSES: ECE 382 and ECE 404 (or equivalent), or permission of instructor.

PREREQUISITES BY TOPIC:
1. Electric field, power, and intensity of EM fields in linear materials.
2. Working knowledge of quantum mechanics; in particular, time-dependent perturbation theory.

DETAILED COURSE TOPICS:
Wave equation with nonlinear polarization
Microscopic origin of nonlinear susceptibility
Properties of susceptibility tensor
$\chi^{(2)}$ phenomena:
- electro-optic effect
- second-harmonic generation
- sum/difference frequency generation
- parametric amplification
$\chi^{(3)}$ phenomena:
- self-phase modulation, nonlinear refractive index
- cross-phase modulation
- four-wave mixing
- nonlinear birefringence
- solitons
Nonlinear Scattering
- Stimulated Raman scattering
- Stimulated Brillouin scattering

COMPUTER USAGE: Graphical display of the solutions of the pertinent nonlinear equations.

BASIS for GRADE: Tentative breakdown is as follows: Midterm test 30%, term paper and presentation 30%, and final exam 40%. Homework is a factor in borderline decisions.
COURSE TITLE: ECE 410 System Theory

CATALOG DESCRIPTION: Unified treatment of continuous and discrete time systems from a state-variable viewpoint; emphasis on linear systems. Concept of state, writing and solving state equations, controllability and observability, transform techniques (Fourier, Laplace, Z), stability, and Lyapunov's method.


REFERENCE TEXTS: None.

COURSE DIRECTOR: Arthur Butz

COURSE GOALS: Describe linear dynamic systems in terms of state variables and vector-matrix differential equations (continuous time) or difference equations (discrete time). The topics will include concept of linear space and linear operators, matrix algebra, eigenvalues and generalized eigenvectors, matrix functions, representation and solution of state-variable dynamic equations, controllability and observability of linear dynamic systems, and stability considerations.

PREREQUISITES BY COURSES: ECE 360 or equivalent

PREREQUISITES BY TOPIC:

1. Linear algebra
2. Transfer functions of linear time-invariant systems, poles and zeros, Laplace and Z transforms

DETAILED COURSE TOPICS:

1. Introduction to state-space systems, differences between state-space and input-output models of systems
2. Linear state-space models, small-signal linearization, similarity transformations
3. State transition matrices for continuous- and discrete-time linear systems, solutions to state equations
4. Linear time-invariant systems, matrix exponential
5. Computation of matrix exponential via Jordan form and Laplace/Z transforms, functions of a square matrix, Cayley-Hamilton theorem
6. Stability
7. Controllability, observability, and reachability of linear systems
8. Realizability, minimal realizations
9. Canonical realizations, Kalman decomposition

COMPUTER USAGE: at the discretion of the instructor.

LABORATORY PROJECTS: None.

GRADES: Weights on homework, exams, etc. are at the discretion of the instructor.
COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. analyze linear state-space systems in continuous- and discrete time (controllability, observability, reachability, stability.
2. solve linear time-invariant state equations in continuous- and discrete time.
3. obtain state-space realizations of transfer functions and likewise derive transfer functions from state-space descriptions.
COURSE TITLE: ECE 418 Advanced Digital Signal Processing

CATALOG DESCRIPTION: Selected topics in digital signal processing such as digital speech processing, multidimensional digital signal processing, spectrum estimation, and error analysis.

REQUIRED TEXT: None.


COURSE DIRECTOR: Arthur Butz

COURSE GOALS: Basics of multirate DSP. Wavelets and multiresolution analysis and their interpretation and use.

PREREQUISITES BY COURSES: ECE 359 or equivalent.

PREREQUISITES BY TOPIC: Digital Signal Processing

DETAILED COURSE TOPICS:

1. Multirate DSP
2. Wavelet theory
3. Wavelets in software
4. Applications of wavelets

COMPUTER USAGE: Matlab is used to generate and process wavelet transforms.

LABORATORY PROJECTS: See Computer Usage.

GRADES:
Homework – 25%
Exams – 75%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Analyze multirate DSP systems.
2. Determine coefficients for perfect reproduction filter banks and wavelets.
3. Choose parameters to take a wavelet transform, and interpret and process the result.
COURSE TITLE: ECE 420 Digital Image Processing


REFERENCE TEXTS: None.

COURSE DIRECTOR: Aggelos Katsaggelos

COURSE GOALS: To study the application of digital signal processing to problems in image processing. Topics covered will range from the fundamentals of 2-D signals and systems, to image enhancement, restoration and compression. A brief coverage of video processing (compression) will also be given.

PREREQUISITES BY COURSES: ECE 359 or equivalent.

PREREQUISITES BY TOPIC: Introduction to digital signal processing.

DETAILED COURSE TOPICS:

2-D Signals and Systems
- Description and Properties of 2-D signals and systems
- 2-D Fourier Transform
- 2-D DFT and FFT
- Rectangular sampling
- Arbitrary sampling

Enhancement and Restoration
- Contrast and dynamic range modification
- Edge detection
- Degradation models
- Noise filtering
- Deterministic restoration filters
- Stochastic restoration filters

Image Compression
- Quantization
- Lossless coding
- Predictive coding
- Transform coding
- Standards (JPEG)
- Fractal coding
Video Compression
   Motion estimation
   Transform coding
   Standards (MPEG, H.261, H.263)

**COMPUTER USAGE:** None.

**LABORATORY PROJECTS:** None.

**GRADES:**

Homeworks – 30%
Midterm Exam – 30%
Final Exam – 40%

**COURSE OBJECTIVES:** When a student completes this course, s/he should be able to:

1. Understand the fundamental concepts of 2D signals and systems;
2. Perform image enhancement and restoration;
3. Perform image compression and decompression;
4. Perform video compression and decompression.
COURSE TITLE: ECE 422 Random Processes in Communications and Control I

CATALOG DESCRIPTION: Fundamentals of random variables; mean-squared estimation; limit theorems and convergence; definition of random processes; autocorrelation and stationarity; Gaussian and Poisson processes; Markov chains.


REFERENCE TEXTS:


COURSE DIRECTOR: Abraham Haddad

COURSE GOALS: To provide entering graduate students with a broad coverage of random processes that will serve as a foundation for advanced courses in their specializations, particularly in control, communications, networks, and signal processing.

PREREQUISITES BY COURSES: One course in probability.

PREREQUISITES BY TOPIC:

1. Probability theory.
2. Frequency spectrum, Fourier transforms.

DETAILED COURSE TOPICS:

Week 1: Review of probability theory.
Week 2: Review of random variables.
Week 3: Multiple random variables.
Week 4: Limit theorems and estimation.
Week 5: Introduction to random processes.
Week 6: Properties of random processes.
Week 7: Spectral properties.
Week 8: Gaussian and Poisson processes.
Week 9: Markov chains.
Week 10: Basic queueing models.

COMPUTER USAGE: Optional.
LABORATORY PROJECTS: None.

GRADES:

Homework – 30%
Midterm – 30%
Final – 40%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Understand the description and behavior of random processes.
2. Model and analyze systems with random signals.
COURSE TITLE: ECE 425 Quantum Electronics II: Quantum Theory of Semiconductor Laser, Microcavity, and Nanophotonics

CATALOG DESCRIPTION: Introduction to semiclassical and fully quantized theory of laser leading to noise, coherent, and modulation properties of laser light, with emphasis on semiconductor laser. The quantum concept of photon and photodetection will be formulated. The theory will be applied to describing noise in optical amplifier and photodetection. The effect of optical feedback on laser will be covered. The inhibition and enhancement of spontaneous emission in microcavity and nanophotonic device structures will be discussed.

REQUIRED TEXT: None (lecture notes will be given)

REFERENCE TEXTS:
P. Meystre & M. Sargent III, Elements of Quantum Optics, Springer Verlag, 2nd Edition

COURSE DIRECTOR: Seng-Tiong Ho

COURSE GOALS: To introduce students to the concept of noise in laser and optical amplifier. Both semiclassical and quantum theories of laser will be covered with emphasis on semiconductor laser and applications to microcavity and nanophotonic device structures.

PREREQUISITES BY COURSES: An introductory course in quantum mechanics (e.g. ECE 404 or equivalent) or permission of the instructor.

DETAILED COURSE TOPICS:
2. Coherent, noise, and modulation properties of laser with emphasis on semiconductor laser.
3. Effects of optical feedback on laser.
5. Introduction to quantum theory of laser.
7. Microcavity and nanophotonic structures.
8. Quantum concept of photon and photodetection.

COMPUTER USAGE: None.

LABORATORY PROJECTS: None.

GRADES:
Homeworks – 30%
Midterm Exam – 30%
Final Exam – 40%
**COURSE OBJECTIVES:** When a student completes this course, s/he should be able to:

1. Understand the semiclassical theory of laser.
2. Understand the coherent, noise, and modulation properties of laser light.
3. Understand the effect of optical feedback on laser.
4. Know the origin of noise in optical amplifier.
5. Understand the quantum theory of laser.
6. Understand the quantum states of laser light.
7. Know how microcavity and nanophotonic structures modify spontaneous emission.
8. Have a better understanding of the quantum concept of photon and photodetection.
COURSE TITLE: ECE 427 Optical Communications

CATALOG DESCRIPTION: Optical communication systems, optical wave propagation, photodetection statistics, heterodyne receiver, and noise sources. Evaluation of communication performance for the free-space channel. Introduction to fiber optic communication and fiber optic networks.


REFERENCE TEXTS: Lectures Notes by J.H. Shapiro, M.I.T.

COURSE DIRECTOR: Horace Yuen

COURSE GOALS: To provide a basic knowledge of optical communication system analysis.

PREREQUISITES BY COURSES: ECE 302 and 307

PREREQUISITES BY TOPIC:

1. Probability
2. Communications

DETAILED COURSE TOPICS:

Week 1: General introduction, system issues
Week 2: Loss, dispersion, and modes in optical fibers
Week 3: Photodetection, Poisson statistics and point processes
Week 4: Direct detection receiver and digital signaling
Week 5: Signal-to-noise ratio analysis, system example
Week 6: Homodyne and heterodyne detection
Week 7: Linear amplifiers and amplifier chain
Week 8: Local area network, topology and use of amplifiers
Week 9: Introduction to optical network issues
Week 10: Selected topics, review

GRADING POLICY:

Homework- 50%
Exams- 50%

COURSE OBJECTIVES: When a student completes this course s/he should:

1. understand the underlying issues in optical communications.
2. perform basic analysis of simple communication systems.
COURSE TITLE: ECE 428 Information Theory

CATALOG DESCRIPTION: Information measures and their properties: entropy, divergence, mutual information, channel capacity. Shannon’s fundamental theorems for data compression and coding for noisy channels. Applications in communications, statistical inference, algorithmic complexity, probability, and finance.


REFERENCE TEXTS:

COURSE DIRECTOR: Dongning Guo

COURSE GOALS: To provide students with an understanding of basic information theoretic techniques and results. To demonstrate the application of information theory to data compression, reliable communications, statistical inference, algorithmic complexity, probability, and finance.

PREREQUISITES BY COURSES: 302.

PREREQUISITES BY TOPIC:

1: Good understanding of basic probability.
2: Mathematical maturity.

DETAILED COURSE TOPICS:

1. Information measures (entropy, divergence, mutual information) and basic properties.
2. Typical sets and the Asymptotic Equipartition Property.
4. Data compression/lossless source coding.
6. Optimal gambling, algorithmic complexity.
7. Channel coding, information capacity.
8. The channel coding theorem for discrete memoryless channels.
9. Converse to the channel coding theorem, joint source channel coding, feedback capacity.
10. Discrete and continuous-time Gaussian channels, band-limited channels.

COMPUTER AND LABORATORY PROJECTS: None.
GRADES:
Homeworks – 30%
Midterm – 30%
Final Exam – 40%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Understand the basic information measures and their properties.
2. Understand the objectives of source and channel coding;
3. Understand fundamental limits on data compression and rates for reliable data communication.
4. Understand basic applications of information theory to communications, statistical inference, computing and finance.
COURSE TITLE:  ECE 429 Selected Topics in Quantum Information Science and Technology

CATALOG DESCRIPTION:  Basic general principles of quantum mechanics for applications to quantum information science and technology. The fundamentals will be covered together with topics of current interest among the areas of quantum teleportation, quantum computation, and quantum cryptography.


COURSE DIRECTOR:  Horace Yuen

COURSE GOALS:  To introduce the basic concepts and techniques underlying all quantum information science and technology, and topics of current interest in one or more of the following areas: quantum computation, quantum information and communication, quantum cryptography.

PREREQUISITE BY TOPIC:  Knowledge of quantum mechanics and permission of instructor.

DETAILED COURSE TOPICS:
1. General formulation of quantum physics, relation to quantum information
2. Quantum computation and quantum algorithms, models of quantum computation
3. Quantum information processing, quantum noise and operations
4. Quantum cryptographic protocols, key distribution and privacy. Authentication
5. Selected in-depth topics in the areas of quantum computation, quantum information processing, and quantum cryptography
COURSE TITLE: ECE 432 Advanced Computer Vision

CATALOG DESCRIPTION: Advanced topics in computer vision including low-level vision, geometrical and 3D vision, stereo, 3D scene reconstruction, motion analysis, visual tracking, object recognition and human motion analysis, capturing and recognition, with the applications to video processing and vision-based modeling and interaction.

REQUIRED TEXT: None


REFERENCE TEXTS:
(3) B.Horn, "Robot Vision", MIT Press, 1986

READINGS: Papers from journals and conference proceedings.

COURSE DIRECTOR: Ying Wu

COURSE GOALS: To gain a profound understanding of the theories, algorithms of the state-of-the-art of computer vision, various mathematical approaches, and the applications to video processing and vision-based modeling and interaction. This is a research-orientated course.

PREREQUISITES BY COURSES: ECE 230, ECE302, and ECE332, or equivalent

PREREQUISITES BY TOPIC:
(1) Linear algebra and probability
(2) Digital image analysis and processing
(3) C/C++, MATLAB

DETAILED COURSE TOPICS:
(1) Camera models and image formation
(2) Low-level visual processing and texture
(3) Radiometry, BRDF, color and lighting
(4) Segmentation and grouping
(5) Optical flow and motion analysis
(6) Visual tracking, Kalman filtering and Sequential Monte Carlo
(7) Deformable and articulated motion analysis
(8) Geometry, stereo, structure from motion
Scene modeling and 3D reconstruction
Useful statistical learning techniques (including HMM, Bayesian Nets, SVM, ICA)
Pattern recognition and object recognition
Application to vision-based human computer interaction (human motion, face/gesture recognition)

LAB PROJECTS:
1. Implementation of edge and corner detectors
2. Implementation of color-based image segmentation
3. Implementation of flow computation
4. Implementation of image feature matching
5. Ball tracking by Kalman filtering
6. Implementation of PCA and LDA

* MATLAB codes are acceptable.

FINAL PROJECT TOPICS:
1. Surveying the state-of-the-art of any topic in vision
2. Facial feature tracking (test sequence provided)
3. Face detection and recognition (test sequence provided)
4. Multiple moving object tracking (test sequence provided)
5. Simple gesture/action recognition (test sequence provided)
6. Stereo, 3D reconstruction and image mosaic (test sequence provided)
7. Algorithms for some learning tasks (data sets provided)
8. Image or texture classification (databases provided)
9. Implementation of any interesting vision algorithm
10. Anything that you think is NEW!

GRADES:
1. Homeworks and labs --- 30%
2. Final Projects and presentations --- 70%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:
1. Understand the core theories and algorithms of computer vision and video processing
2. Understand the state-of-the-art of computer vision and image/video processing,
3. Perform image feature detection/matching and 3D scene reconstruction,
4. Perform visual tracking and motion analysis,
5. Perform visual object recognition and motion recognition tasks,
6. Understand the applications such as vision-based modeling and interaction.
COURSE TITLE: ECE 435 Neural Networks

CATALOG DESCRIPTION: Learning in one-layer and multi-layer feed-forward networks, recurrent networks and dynamical systems. Hopfield networks, self-organizing maps, radial basis functions, support vector machines, stochastic machines, and applications (pattern recognition, signal processing, control, and others).


COURSE DIRECTOR: Wei-Chung Lin

COURSE GOALS: The goal of this course is to provide students with a basic understanding of the fundamentals and applications of artificial neural networks.

PREREQUISITES BY COURSES: Engineering Analysis 1 & 4, ECS 230 or 231 or equivalent, ECE 302.

PREREQUISITES BY TOPIC: Linear Algebra, Differential Equations, Probability, Computer programming in C++.

DETAILED COURSE TOPICS:
1. Introduction to artificial neural networks, data fitting with linear models (1 week)
2. LMS algorithm, foundations of artificial neural networks (1 week)
3. Perceptrons, multilayer perceptrons, back-propagation networks (1 week)
4. Designing and training multilayer perceptrons, functional approximation with multilayer perceptrons (1 week)
5. Radial-basis function networks, support vector machines (1 week)
6. Hebbian learning, principal component analysis (1 week)
7. Kohonen self-organizing maps
8. Neurodynamics and Hopfield networks (1 week)
9. Stochastic machines, counterpropagation networks

COMPUTER PROJECTS: Projects on implementation of some neural network models and their applications to real-world problems will be assigned throughout the quarter.

GRADES:
Mid-term exam – 30%
Homework assignment – 40%
Final Exam – 30%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:
1. Understand the mathematical foundations of neural network models.
2. Design and implement neural network systems to solve real-world problems.
COURSE TITLE:  ECE 438-1,2,3 Interdisciplinary Nonlinear Dynamics

CATALOG DESCRIPTION:  438-1: Example-oriented survey of nonlinear dynamical systems, including chaos, combining numerical, analytical and geometrical approaches to differential equations.  438-2,3: Interdisciplinary theoretical, computational and experimental projects involving complex systems in science and engineering, directed by a cross-disciplinary faculty team.


COURSE DIRECTOR (ECE):  Prem Kumar

DETAILED COURSE TOPICS:

This course will constitute a core element of the new NSF/IGERT program *Dynamics of Complex Systems in Science and Engineering*. It will start as a lecture-based course in fall. In the winter and spring quarter it will evolve into a projects-based course.

I. Lecture Course in Fall Quarter

The class will meet twice a week. Lectures will often include numerical demonstrations. There will be regular homework assignments, which will include analytical and numerical work. The latter will be done mostly using Matlab. The homework will be graded by teaching assistants, who will also lead discussion/tutorial sections. The teaching assistants will be senior students in the NSF/IGERT program *Dynamics of Complex Systems in Science and Engineering*.

Course Outline:

1. Introduction
   Basic properties of differential equations: linear vs. nonlinear.
   Reading: Ch. 1, 2.0-2.2

2. One-dimensional Flow
   Fixed points and stability, linear stability analysis, impossibility of oscillations, numerical methods.
   Reading: Ch. 2.3-2.8

3. Bifurcations
   Implicit-function theorem, saddle-node bifurcation, transcritical bifurcation, laser threshold.
   Reading: Ch. 3.0-3.3

4. Bifurcations
   Pitchfork bifurcation, imperfect bifurcations and catastrophes, insect outbreak.
   Reading: Ch. 3.4-3.7
5. Flows on the Circle
Uniform and nonuniform oscillator, bifurcation, overdamped pendulum, superconducting Josephson junction.
Reading: Ch. 4

6. Two-dimensional Flows
Classification of linear systems.
Reading: Ch. 5

7. Phase Plane
Phase portraits, fixed points and linearization, attractors and basin of attraction, pendulum.
Reading: Ch. 6

8. Limit Cycles
Ruling out oscillations: Lyapunov functions, Poincare-Bendixson theorem: no chaos in two dimensions.
Reading: Ch. 7.0-7.3, 7.5

9. Weakly Nonlinear Oscillators
Regular perturbation theory and its break-down, two-timing, averaged equations.
Reading: Ch. 7.6

10. Bifurcations in 2 Dimensions
Hopf bifurcation. Complex amplitude equation in the vicinity of the bifurcation.
Reading: Ch. 8

11. Bifurcations in 2 Dimensions
Pitchfork bifurcation: separation of time scales. Stable, unstable, and center manifold. Center manifold reduction.
Reading: Ch. 8

12. Bifurcations and Partial Differential Equations
Reading: tba

13. Large-scale Dynamics of Patterns
Reading: tba

14. Lorenz Equations
Model for convection, water wheel. Dissipation and phase-space volume contraction. Fixed points and limit cycles.
Reading: Ch. 9.0-9.2
15. Lorenz Attractor
Strange attractor, sensitive dependence on initial conditions, Lyapunov exponents, Lorenz map.
Reading: Ch. 9.3-9.5

16. One-dimensional Maps
Reading: Ch. 10.0-10.4

17. One-dimensional Maps
Scaling of the period-doubling cascade. Renormalization and universality. One-dimensional maps and experiments.
Reading: Ch. 10.5-10.7

18. Strange Attractors
Reading: Ch. 11

19. Diagnostic Tools
Comparison with experiments.
Reading: Ch. 12

20. Outlook
Excitable systems, localized pulses. Spatio-temporal chaos.

II. Project-Based Course in Winter and Spring Quarters

In the Winter and Spring quarters the students will split into two or three project-focused teams comprised of approximately five students each and supervised by two faculty members with complementary expertise and perspectives. A non-exhaustive list of examples of research areas from which the themes for the projects may be chosen are listed below. The students in a given team will focus on one theme, with each student pursuing his or her own project as part of the larger group effort; this ensures that each student learns all aspects of a specific area, while still gaining valuable team-work experience. For example, some students may set out to reproduce theoretical results of research papers in the literature, with the ultimate goal of adding their own contributions to the topic, while other students may read and critique experimental papers, before going on to do laboratory work related to the team research theme. Progress in nonlinear science rests on the close interplay among theory, experiment, and computation. This will be reflected in the course by including a strong computational component in each student's experimental and/or theoretical project.

Background material that is relevant to all students in a team will be addressed in weekly group meetings; the role of discussion leader will rotate among the students and faculty in the group. In these meetings the students will also briefly report on progress in their work and on possible difficulties. This gives the students ample opportunity to practice their presentation skills and to
incorporate the feedback they receive from their fellow students and the mentoring faculty in preparing their final project presentation.

In addition to the weekly meetings of the teams, there will be a weekly meeting of all students and faculty participating in the course. There will be one primary faculty member who will coordinate this aspect of the course, although responsibility for the common lectures will cycle between the groups. Initially, for instance, the faculty may take a lead in the class meetings by giving some overview lectures of their team's research area. As the students progress in their own work, they will start presenting the highlights in the style of a journal-club presentation. These presentations will provide the background for the capstone of the course: the final presentations by the students in each of the teams. A class discussion following each presentation will give students valuable feedback that they can take into account in preparing their final written project report.

Non-exhaustive List of Themes:

1. **Pattern Formation:**
   Students will investigate pattern formation in physical, chemical, or biological systems. This could, for instance, be wave patterns in periodically forced systems (e.g. surface waves on liquids or granular media) or waves in excitable media (e.g. in the heart, neurons, EEG-activity). The investigations will include analytical and computational work as well as experiments in the lab of Prof. Umbanhowar.

2. **Neurocontrol of Biomorphic Systems:**
   The projects will combine concepts and tools of theoretical neurocomputing and nonlinear adaptive control in nonlinear limb dynamics, and apply them to the control of a biomimetic robotic system in the lab of Prof. Mussa-Ivaldi.

3. **Solitons and Solitary Structures:**
   The projects will focus on localized structures in optical and other physical or chemical systems. Students will set up experiments on soliton propagation in optical fibers in the lab of Prof. Kumar. Comparison with theory will involve numerical simulations of the corresponding analytical models of nonlinear pulse propagation. The behavior of nonlinear waves in optical systems will be contrasted with their behavior in other physical and biological systems.

4. **From Low- to High-Dimensional Chaos:**
   Each project will require mastery of the same basic set of techniques of the theory of low-dimensional chaotic systems, including computation and graphical visualization. Applications may be as varied as neurophysiological experiments, analysis and experiments of mixing in fluids and granular material, or numerical simulations and analysis of spatiotemporal chaos.
COURSE TITLE: 452 Advanced Computer Architecture I

CATALOG DESCRIPTION: Design and evaluation of modern uniprocessor computing systems. Evaluation methodology/metrics and caveats, instruction set design, advanced pipelining, instruction level parallelism, prediction-based techniques, alternative architectures (VLIW, Vector and SIMD), memory hierarchy design, I/O, and recent trends in architecture (e.g., low-power architectures, application-specific processors). Case studies.

REQUIRED TEXT: None


COURSE DIRECTORS: Gokhan Memik

COURSE GOALS: Learn how to build the best processor/computing system understanding the underlying tradeoffs and ramifications.

PREREQUISITES BY COURSES: ECE 361 or consent of the instructor.

PREREQUISITES BY TOPIC: Basic notions of computer architecture including programs, instruction sets, simple processor design and memories.

DETAILED COURSE TOPICS:

Week 1: Review of basic system design, technology, evaluation methodology. Metrics: performance, cost and power.
Week 2: Instruction set architecture: implications and interaction with compilers.
Week 3: Advanced Pipelining and introduction to instruction-level parallelism.
Week 4: Instruction-level parallelism, superscalar processor design, register renaming and precise interrupt handling.
Week 5: Branch prediction, related static/dynamic techniques and other prediction-based techniques.
Week 6: VLIW, vector processors, multimedia targeted instruction sets. Memory system design introduction.
Week 7: Memory system design: memory operation scheduling/memory renaming, advanced caches, pre-fetching, main memory systems, modern DRAM technologies.
Week 8: Virtual memory support. I/O.
Week 9: Technology forecasts, state-of-the-art in modern processor design and case studies.
Week 10: Project Presentations.

COMPUTER USAGE: As required for the course project and assignments.
**LABORATORY PROJECT:** An extensive individual or group project on an advanced topic in computer architecture. While, a list of suggested project topics will be provided, students are strongly encouraged to suggest a project of their own. The default project is to do some *original* research in a group of two to three students. Alternatively, a student may work alone on a survey.

**GRADES:**

- 50% Project
- 30% Final
- 10% Homework assignments
- 10% Class Participation

**COURSE OBJECTIVES:**

To provide students with: (1) a broad understanding of computer architecture and, (2) to the extent possible, an understanding of the current state-of-the-art in uniprocessor computer architecture. In 361 students learn how to build a working computer. In this course, we go a step further and study how to use technology to build the “best” computer/processor.

Specifically, upon completion of this course, a student should have developed:

1. Broad understanding of the design of computer systems, including modern architectures and alternatives.
2. Understanding of the interaction amongst architecture, applications and technology.
3. Understanding of a framework for evaluating design decisions in terms of application requirements and performance measurements.
4. A historical perspective on computer system design.
5. Gain experience with using and modifying a state-of-the-art computer simulator.
6. Gain experience on identifying and pursuing a research project.
7. Gain experience with writing a research report.
8. Gain insight on evaluating research papers.
9. Gain experience in technical presentations.
**COURSE TITLE:** ECE 453 Advanced Computer Architecture II

**CATALOG DESCRIPTION:** Parallel computer architecture and programming models. Message passing and shared memory multiprocessors. Scalability, synchronization, memory consistency, cache coherence. Memory hierarchy design. Network design.


**COURSE DIRECTOR:** Russ Joseph

**PREREQUISITES BY COURSES:** ECE 361 or consent of instructor. ECE 452 and ECE 358 are strongly suggested. Basic understanding of VLSI suggested but not required.

**PREREQUISITES BY TOPIC:** Advanced uniprocessor architecture, parallel programming, basic operating systems and compilers.

**DETAILED COURSE TOPICS:**

**Week 1:** Introduction, overview of parallel architectures, fundamental design issues, examples of parallel programs and models. CSG Chapters 1 and 2.

**Week 2:** Workload-driven evaluation, introduction to symmetric multiprocessors and cache coherence. CSG Chapter 3 and 4.

**Weeks 3 and 4:** Symmetric multiprocessors continued: cache coherence, memory consistency, synchronization. Snoop-based multiprocessor design. CSG Chapters 4, 5 and 6.

**Weeks 5 and 6:** Scalable multiprocessors: scalability, programming models, clusters and networks of workstations and directory-based coherence. CSG Chapters 7 and 8.

**Week 7:** Relaxed consistency models and software/hardware tradeoffs. Introduction to interconnection network design.

**Week 8:** Dataflow, SIMD and other alternatives. AG Chapter 10.2.8.

**Week 9:** Research papers, case studies and work on projects.

**Week 10:** Project presentations.

**COMPUTER USAGE:** As required for the course project and assignments.

**LABORATORY PROJECT:** An extensive individual or group project on an advanced topic in parallel computer architecture. The default project is to do some original research in a group of two to three students. Alternatively, a student may work alone on a survey.

**GRADES:**

- 40% Project
- 45% Midterm and Final
- 10% Homework
5% Class Participation

COURSE OBJECTIVES: The goal of this course is to provide students with (1) a broad understanding of parallel computer architecture and (2) to the extent possible, an understanding of the current state-of-the-art in parallel computer architecture.

Specifically, upon completion of this course, a student should have developed:

1. Broad understanding of the design of parallel computer systems, including modern parallel architectures and alternatives.
2. Understanding of the interaction amongst parallel architecture, applications, and technology.
3. Understanding of a framework for evaluating design decisions in terms of application requirements and performance measurements.
4. Gain experience with using and modifying a parallel computer simulator.
5. Gain experience on identifying and pursuing a research project.
6. Gain experience with writing a research report.
7. Gain insight on evaluating research papers.
8. Gain experience in technical presentations.
COURSE TITLE: ECE 454 Modeling and Analysis of Communication Networks


COURSE DIRECTOR: Randall Berry

COURSE GOALS: To introduce students to techniques for analyzing and modeling communication networks. To provide students with background to understand current research on communication networks.

PREREQUISITES BY COURSES: ECE 302 (ECE 333 helpful but not required).

PREREQUISITES BY TOPIC: Main prerequisite is a good understanding of basic probability. Introductory knowledge of communication networks is also helpful.

DETAILED COURSE TOPICS:

Week 1: Distributed algorithms, specification and correctness.
Week 2: Delay models, Little’s theorem, Poisson processes, Markov chains.
Week 3: Markovian systems, Erlang formulas, multi-class loss networks.
Week 4: M/G/1 queues, reservation and polling systems, priority queuing, fair queueing.
Week 5: Queueing networks and reversibility, traffic modeling, long range dependence.
Week 6: Routing and graph theory, spanning tree and shortest path algorithms.
Week 7: Optimal flow-based routing, network design problems.
Week 8: Congestion control, fairness and utility functions, window-based approaches and TCP.
Week 9: Rate-based congestion control, leaky-buckets, deterministic network calculus.
Week 10: Project presentations.

COMPUTER USAGE: Optional.

LABORATORY PROJECTS: Optional.
GRADES:

Homeworks – 25%
Exams – 40%
Final Project – 35%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Understand the analytical tools and conceptual models used in networking performance analysis.
2. Undertake research in the networks field.
COURSE TITLE: ECE 455 Distributed Computing Systems

CATALOG DESCRIPTION: Fundamentals and systems design aspects of distributed systems, paradigms for distributed computing, client-server computing, concurrency control, distributed file systems, resource management, high-performance computing aspects.

REQUIRED TEXTS:

COURSE DIRECTOR: Alok Choudhary

COURSE GOALS: To understand the design of distributed systems and the use of distributed systems in applications.

PREREQUISITES BY COURSES: CS-343 - Operating Systems

PREREQUISITES BY TOPIC: Operating Systems and Programming.

DETAILED COURSE TOPICS:
Week 1: Introduction to distributed systems and networking. Design issues and requirements.
Week 2: Communication and Networking in distributed systems (Layered Protocols, ATMs).
Week 3: Distributed Computing Paradigms: Client-Server model.
Week 4: Distributed Computing Paradigms: Remote Procedure Call (RPC), Message Passing.
Week 5: Distributed File Systems: (Replication, Scalability, Caching for high-performance).
Week 6: Distributed Computing Paradigms: Distributed Shared Memory.
Week 7: Concurrency Control in Distributed Systems.
Week 8: Case Studies of Distributed Systems.
Week 9: World-Wide Web: Design and Technology, World-Wide Web: Servers, Searching for Information and Future Directions.
Week 10: Project Discussions.

COMPUTER USAGE:

1. Clusters

LABORATORY PROJECTS: Students choose projects for the quarter.

GRADES:

Homeworks and Lab Assignment - 25%
Exams 40%
Project 35%
COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Understand basic principles of distributed systems from design to implementation.
2. Use distributed systems for both system level software and applications development.
COURSE TITLE:  ECE 457 Advanced Algorithms

CATALOG DESCRIPTION:  Design and analysis of advanced algorithms: graph algorithms; maximal network flows; min-cost flow algorithms


COURSE DIRECTOR:  Hai Zhou

COURSE GOALS:  This course will cover the theoretical aspects of algorithm design and analysis. Starting with a matching problem, we will first discuss the three central tasks of algorithm design: correctness, termination, and efficiency. Following a similar design process, we will design efficient algorithms for a sequence of problems: shortest paths, minimal cycle ratios, maximal network flows, min-cost flows, and convex cost flows. Besides allowing students to understand those data structures and algorithms, a main goal of this course is to improve the problem solving abilities of the students. Therefore, if possible, we will study together how an efficient algorithm is designed.

PREREQUISITES BY COURSES:  CS336 or any algorithms course.

PREREQUISITES BY TOPICS:  Data structures, Introduction to Algorithms.

DETAILED COURSE TOPICS:

Week 1 Intro to algorithm design: stable marriage

Week 2 Shortest path algorithms

Week 3 Minimal cycle ratio algorithms

Week 4-5 Maximal flow algorithms

Week 6-8 Min-cost flow algorithms

Week 9-10 Convex cost flow algorithms

COMPUTER USAGE:  None.

HOMEWORK ASSIGNMENTS:  Five problem sets and one take-home exam.

LABORATORY PROJECTS:  None.

GRADES:  40% Homework  30% Take-home exam  30% Final exam
COURSE TITLE: ECE 459 VLSI Algorithmics

CATALOG DESCRIPTION: Design and analysis of algorithms for VLSI synthesis problems. Study both theoretical and practical aspects of CAD-tool development in VLSI environments.


COURSE DIRECTOR: Seda Ogrenci Memik

COURSE GOALS: To study algorithmic aspects of high-performance circuit design including architectural design, logic design, physical design, and packaging.

PREREQUISITES BY COURSES: CS 336.

PREREQUISITES BY TOPIC: Basic knowledge of algorithms and some understanding of VLSI CAD.

DETAILED COURSE TOPICS:

Week 1: Introduction
Week 2-3: High-level synthesis: designing a circuit from a high-level description.
Week 4-5: Logic minimization: minimization of resources, at the gate level in a circuit item.
Week 6: Low-power design: how to reduce the power consumption at the behavioral and logic level.
Week 7-8: High-speed design: how to design fast circuits.
Week 9: Design for reliability.
Week 10: Design for testability.

COMPUTER USAGE: Software packages such as SIS and Mentor Graphics’ Monet on workstations.

LABORATORY PROJECTS: Development and implementation of VLSI CAD algorithms in the area of logic synthesis and high-level synthesis.

GRADES:

Homeworks – 35%
Midterm – 30%
Final Project – 35%
COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Design state-of-the-art CAD algorithms in areas of logic synthesis and high-level synthesis with emphasis on area, time, and power minimization.
2. Be able to use state-of-the-art CAD tool for system design.
3. Be able to develop software for solving complex problems in the area of VLSI CAD.
COURSE TITLE: ECE 463: Adaptive Filters

CATALOG DESCRIPTION: applications of adaptive filtering, autoregressive and moving average processes, linear prediction, lattice filters, Least Mean Square (LMS) algorithm, least squares filtering, convergence analysis.


COURSE DIRECTOR: M. Honig

COURSE GOALS: To provide first-year graduate students with an understanding of adaptive filtering applications, structures, algorithms, and performance.

PREREQUISITES BY COURSES: 359, 422

PREREQUISITES BY TOPIC:

ITEM 1: Probability and random processes
ITEM 2: Frequency-domain (spectral) analysis
ITEM 3: Familiarity with z-transforms.

COURSE TOPICS:

1. Applications of adaptive filters
2. Autoregressive and Moving Average processes
3. Linear prediction and joint process estimation
4. Lattice filters
5. Gradient and stochastic gradient (Least Mean Square) algorithms
6. Minimum output energy methods
7. Least squares filtering
8. Convergence analysis
9. Reduced-rank filtering

COMPUTER PROJECTS: Optional.
LABORATORY PROJECTS: None.

GRADES: A weighted combination of homework, midterm, and final.

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Compute optimal linear prediction filters from second-order input statistics.

2. Design an LMS algorithm to meet convergence and steady-state performance constraints.

3. Design an adaptive lattice filter, both for prediction and joint-process estimation.

4. Design a computationally efficient Least Squares filter for different applications.

5. Specify convergence and steady-state performance of the preceding techniques by either analysis or simulation.
COURSE TITLE: ECE 479 Nonlinear Optimization

CATALOG DESCRIPTION: Numerical solution of unconstrained optimization problems, nonlinear least squares and nonlinear systems of algebraic equations, large-scale nonlinear optimization, quadratic programming, and constrained optimization.


COURSE DIRECTOR: Jorge Nocedal

COURSE GOALS: Demonstrate the formulation, solution and analysis of optimization problems. Illustrate the difference between well-posed and ill-posed problems, and the analytical tools to examine the validity of the model and the meaning of the solution. Study modern algorithms for the solution of nonlinear optimization problems.

PREREQUISITES BY COURSES: IE 311, ECE 328

PREREQUISITES BY TOPIC:

1. Basic knowledge of Calculus and Linear Algebra
2. Programming experience

DETAILED COURSE TOPICS:

Week 1 Modeling Practical Problems
Week 2 Fundamentals of Unconstrained Minimization
Week 3 Line Search Methods
Week 4 Trust Region Methods
Week 5 Practical Newton Methods
Week 6 Differentiation
Week 7 Theory of Constrained Optimization
Week 8 Overview of Constrained Algorithms
Week 9 Sequential Quadratic Programming
Week 10 Augmented Lagrangian Methods

COMPUTER USAGE:

1. Four or five computer projects will be given.
2. Use of Matlab to facilitate analysis of data and the creation of graphics is encouraged.

LABORATORY PROJECTS: None.
GRADES: Homeworks – 100%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:

1. Know how to model optimization problems and understand the distinction between linear, nonlinear and convex problems.
2. Perform sensitivity analysis of models and suggest improvements in the model. Know the types of algorithms that are effective for each class of problems and understand their limitations.
COURSE TITLE: ECE 493 Design and Analysis of High-Speed Integrated Circuits

CATALOG DESCRIPTION: Issues that arise in the design and analysis of VLSI circuits at high speeds such as buffer sizing, repeater insertion, noise, electromigration, Elmore delay, scaling trends, and power consumption.

REQUIRED TEXTS: None.

REFERENCE TEXTS: Papers distributed in class.

COURSE COORDINATOR: Yehea Ismail

COURSE GOALS: To discuss issues that arise in the design and analysis of VLSI circuits at high speeds. The course also aims to help students acquire the basic skills for graduate study such as collecting technical materials, reading and writing papers, and presentation skills.

PREREQUISITES: ECE 391 or equivalent

DETAILED COURSE TOPICS:
1. Review of basic concepts in CMOS circuits
2. Technology scaling trends in CMOS circuits
3. Dynamic, short-circuit, and leakage power consumption of CMOS circuits
4. Cascaded buffer design for driving large capacitive loads and repeater insertion within $RC$ interconnect
5. Design and analysis of integrated circuits including the inductance of the interconnect
6. Characterizing the delay and power consumption of CMOS gates driving $C$, $RC$, and $RLC$ loads.
7. Approximate temporal information in $RC$ and $RLC$ trees (Elmore, Wyatt, Penfield-Rubinstein delay models, and equivalent Elmore delay for $RLC$ trees)
8. Accurate temporal information in $RC$ and $RLC$ trees (model order reduction techniques such as AWE and DTT)
9. Power distribution network design, electromigration, $L_{di/dt}$ noise, and $RI$ drops
10. Coupling and simultaneous switching noise
11. High-speed clock distribution network design: Retiming, register allocation, skew control, and clock scheduling.

PROJECTS:
Each student is required to select a topic for which s/he finds related technical papers and information, gives a presentation in front of the class about the selected topic, and writes a paper that summarizes the research area. A list of topics to choose from will be given at the beginning of the class. Also, students are allowed to suggest their own topics if enough interest in these topics exist.
GRADES:
Topic presentation: 20%
Summary paper: 20%
Class attendance and contribution: 10%
Midterm Exam: 15%
Final Exam: 20%
Homeworks: 15%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:
1. Understand the issues that arise in integrated circuits at high speeds.
2. Identify and deal with the state of art problems in VLSI.
3. Improve his/her presentation style.
4. Read and write technical papers.
5. Pursue research and development in the area of high-speed integrated circuits either in academia or in industry.

ABET CONTENT CATEGORY: 100% Engineering.
COURSE TITLE: ECE 510-2 Seminar – Power and Reliability in Architecture (Fall 2005)

CATALOG DESCRIPTION: This is a new seminar course which will explore advanced topics in two broad areas that will have a significant influence in computer systems design over the next decade: power related issues (energy/temperature) and reliability. This course is geared to graduate students in computer systems (architecture, VLSI/CAD, operating systems, programming languages/compiler design), but undergraduates with an interest and suitable background may also enroll with permission of the instructor.

REQUIRED TEXT: None.

REFERENCE TEXT: Course handouts

COURSE COORDINATOR: Russ Joseph

COURSE GOALS: The main learning vehicles will be readings of classic and recent research papers on both topics, followed by in-class discussions and critiques. Students will be expected to participate in all in-class sessions and occasionally lead a discussion. In addition, students will be required to write short (one-page) critical analyses of the research papers.

PREREQUISITES BY COURSES: Permission by instructor for undergraduates

PROJECT: Students will be required to write short (one-page) critical analyses of the research papers.

GRADES: Critical Analyses 50%
       In-Class Presentations 25%
       Class Participation 25%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:
1. Critique research papers in computer systems and engineering.
2. Understand fundamental issues in power and reliability in current and future technologies.
3. Discuss important innovations and evolutions in power management and reliability.
4. Describe how reliability and power goals and solution techniques interact with each other and with performance.
COURSE TITLE: ECE 510 Digital Video Processing

CATALOG DESCRIPTION: Fundamentals of digital video processing: Digital video standards; image formation models; spatio-temporal sampling; parametric motion models; motion analysis; motion-compensated filtering, noise reduction, deinterlacing, and interpolation; stereo processing; spatio-temporal segmentation; video compression. Related applications, such as digital television, video conferencing, and content-based retrieval will be discussed.


COURSE DIRECTOR: Thrasyvoulos N. Pappas

COURSE GOALS: To provide a thorough background in the fundamental principles and techniques in digital video processing, analysis, and compression, an overview of the current video standards and technologies, and directions for future research.

PREREQUISITES BY COURSES: ECE 359 or equivalent or permission of the instructor.

DETAILED COURSE TOPICS:

- Analog and digital video standards.

- Spatio-temporal sampling.

- Motion analysis:
  + Optical flow methods
  + Block-matching methods
  + Pixel-recursive methods
  + Parametric motion modeling
  + Background subtraction
  + Spatio-temporal segmentation

- Video processing
  + Motion-compensated filtering
  + Noise reduction
  + Superresolution
  + Deinterlacing
  + Motion-compensated interpolation
- Video processing for compression and communication
  + MPEG-1 and MPEG-2
  + H-264
  + Scalable compression
  + Object-based compression
  + Error-resilient coding
  + Video over wireless
  + Digital TV and HDTV
  + Perceptual quality metrics

PROJECT: A bibliographical search or computer type project is required. The purpose of this project is to enhance the understanding of a topic covered in class or to investigate a topic not covered in class. A final written report and a presentation are required.

GRADES: Homework - 30%
  Midterm - 30%
  Project - 40%

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:
1. Understand the fundamentals of digital video processing.
2. Understand the basic principles and techniques for motion analysis.
3. Understand the basic principles and techniques for video filtering, noise reduction, interpolation, deinterlacing, and superresolution.
4. Understand the basic video processing techniques for compression and communication.
5. Apply the acquired knowledge to specific video processing related problems and projects at work.
6. Be prepared for advanced research or development in this area.
COURSE TITLE: ECE 510-4 Nonlinear Control Theory

CATALOG DESCRIPTION: Analysis and design of nonlinear feedback control systems, including Lyapunov methods, input-output methods, dissipation and storage functions, absolute stability, perturbation methods, and others.

REQUIRED TEXTS: None.


COURSE COORDINATOR: Randy Freeman

COURSE GOALS: Students learn basic mathematical tools for the design and analysis of nonlinear control systems.

PREREQUISITES: ECE 360 and ECE 410 or equivalent

PREREQUISITES BY TOPIC:
1. Calculus and ordinary differential equations
2. Linear state-space system theory
3. Analysis and design of linear control systems

DETAILED COURSE TOPICS: To be determined.

COMPUTER USAGE: MATLAB/Simulink

LABORATORY PROJECTS: None.

GRADES: To be determined.

COURSE OBJECTIVES: When a student completes this course, s/he should be able to:
1. analyze the stability and other qualitative properties of closed-loop systems,
2. numerically simulate the behavior of nonlinear control systems,
3. design controllers to meet a variety of performance objectives, and
4. read and understand current research literature in the field.
COURSE TITLE: ECE 510-5 Adaptive Embedded Operating Systems

CATALOG DESCRIPTION: Seminar series on research at the boundaries between operating systems and each of the following areas: embedded systems, architecture, computer-aided design, VLSI design, and signal processing. Study will focus on operating system techniques for prediction of, adaptation to, and control of the dynamically changing conditions of hardware and applications.

REQUIRED TEXT: A number of research articles will be read and discussed.

REFERENCE TEXTS:

COURSE COORDINATOR: Robert Dick

COURSE GOALS: To establish an understanding of recent research on the use of operating system and compiler techniques for predicting and controlling the behavior of general-purpose and application-specific processors in order to improve reliability, thermal profile, power consumption, and/or performance, etc., and use this knowledge as a foundation for new work in the area.

PREREQUISITES BY COURSES: None.

PREREQUISITES BY TOPICS:
1. Operating systems
2. Computer architecture

PROJECTS: Each student will perform a project on a topic relevant to the course. This will include the following tasks: finding and reading pertinent research papers and other technical information, writing a project proposal, completing the project, and presenting the results to the class. A list of valid topics will be supplied although the students will be encouraged to select a topic of personal interest.

GRADERS:
1. Research paper summaries and observations – 40%
2. Project – 45%
3. Presentation – 15%

COURSE OBJECTIVES: Students completing this course should be able to
1. Understand the interaction among operating systems, hardware, and applications.
2. Determine the feasibility, costs, and benefits of implementing functionality at the application, operating system, and hardware levels.