Computer and Information Science

Faculty and Fields of Interest

Students who major in computer science are given a strong background in computer hardware and software, as well as a substantial amount of "hands-on" experience. They are prepared to work both in computer industry and business as well as pursue graduate studies in the discipline. Both major and minor programs are offered.

The undergraduate program is accredited by the Accreditation Board for Engineering and Technology (ABET).

Qualified computer science majors can benefit from the Cooperative Education program offered in cooperation with the local computer industry.

The CIS department also offers a Master of Science Degree in Computer Science with a broad range of required and elective courses in theoretical computer science, computer systems, software engineering, parallel and distributed computing, and computer networks. See the *Graduate Catalogue* for information.

Emad H. Aboelela computer networks, fuzzy systems

Ramprasad Balasubramanian computer vision, motion detection, image processing

Jan Bergandy distributed systems, software engineering, theoretical computer science

Paul Bergstein object-oriented programming, databases

Eugene Eberbach evolutionary computing, concurrent systems, artificial intelligence

Robert Green software engineering, parallel architectures (on leave, associate provost for computer and information technology)

Adam O. Hausknecht symbolic manipulators, foundations of computer science

Anish Mathuria communication protocols, computer networks

Boleslaw Mikolajczak (chairperson) algorithms and complexity, parallel and distributed processing, computer architecture, theoretical computer science

Edmund B. Staples analysis of algorithms, mathematical applications, logical methods, and complexity theory

Richard Upchurch social implications, software engineering, human-computer interaction

Iren Valova artificial intelligence, neural networks, image processing

Faculty with Computer and Information Science Joint Appointment
Primary Department

Adam Hausnecht
Mathematics

Department Mission

- To offer the strongest Bachelor of Science degree program in Computer Science in the state of Massachusetts
- To define and develop graduate programs in Computer Science of intellectual rigor which meet regional needs
- To develop a Computer and Information Science research program appropriate to the University
- To meet regional and state needs through education, and industrial and community outreach
- To build a satisfying and career enhancing environment at UMD
- To help build an interdisciplinary intellectual environment at UMD
- To develop curricula to meet the computer fluency needs of all UMD students.

Program Goals

Graduates who succeed as practicing computer scientists.
Graduates who succeed in advanced study in computer science.
Graduates who adapt and evolve in complex technological environments such as those found in the workplace.
Graduates who influence the development of professional, ethical and legal aspects of computing.

Program Outcomes

To meet the program goals the Computer and Information Science Department, through its major in computer science, produce graduates who:

- are able to individually solve problems in algorithmic manner with given computer resources and constraints;
- apply their knowledge of mathematics, science and computer science to solve technical problems;
- apply analytic and empirical techniques to evaluate technical problems and their solutions;
- design system, component, or process to meet specified requirements;
- participate as a member of a multidisciplinary, problem solving team;
- identify, formulate, and solve problems encountered when constructing solutions involving information technology;
- articulate the social, professional, ethical and legal aspects of a computing milieu;
- evaluate the impact of computing and information technology at the global/societal level;
- analyze contemporary issues related to the evolving discipline of computer science;
- communicate effectively (needs to be understood as involving both orally and written, and include choosing and using the appropriate representations and/or media);
- apply modern skills, techniques, and tools during professional practice.

Computer Science Major

BS degree

A wide selection of courses offers experience in software engineering, computer languages, artificial intelligence, compilers, computer networks, operating systems, computer architecture, computer graphics, parallel computing, human computer interaction and data bases, as well as theoretical aspects. The undergraduate computer science curriculum is object-oriented, lab intensive, and directed toward software development. The courses are supported by a network of state-of-the-art workstations and various specialized laboratories.

The Computer Science bachelor's degree program is accredited by the Computing Accreditation Commission of the Accreditation Board of Engineering and Technology (CAC/ABET, www.abet.org).

General Education Departmental Requirements

Students majoring in Computer Science will meet their departmentally-controlled General Education requirements as follows:

Area E: Satisfied by CIS 381
Area I, Tier 2: Satisfied by any CIS course above CIS 110
Area W, Tier 2: Satisfied by ENL 266
Area O: Satisfied by CIS Technical Electives, CIS 362 and 480

Requirements

Semester Credits

Computer Science majors must fulfill the following requirements. In addition, all Computer Science majors must complete the CIS Department Exit Survey in their final semester.

1.
Complete the following CIS core courses, each with a grade of "C" or better.

CIS 180	Object-Oriented Programming	4
CIS 181	Programming Paradigms	4
CIS 190	Introduction to Procedural Programming	4
CIS 272	Introduction to Computing Systems	4
CIS 273	Computer Organization and Design	4
CIS 280	Software Specification and Design	4
CIS 360	Algorithms and Data Structures	3
CIS 361	Models of Computation	3
CIS 370	Design of Operating Systems	4
CIS 480	Software Engineering	4
CIS 481	Parallel & Distrib. Software Systems	3

2.
Complete four additional courses from the following CIS technical electives, each with a grade of 'C' or better:

CIS 314	Computer Architecture	4
CIS 410	Programming Language Design	3
CIS 412	Found. Artificial Intelligence	3
CIS 421	Intro. Theory of Computing	3
CIS 422	Design of Parallel Algorithms	4
CIS 431	Human-Computer Interaction	4
CIS 443	Process-Based Design	3
CIS 452	Database Systems	3
CIS 454	Computer Graphics	3
CIS 465	Topics in Computer Vision	3
CIS 467	Image Analysis and Processing	3
CIS 471	Compiler Design	3
CIS 475	Computer Networks	3

3.
Complete the following Mathematics Requirements:

MTH 111	Analytical Geometry & Calculus I	4
MTH 112	Analytical Geometry & Calculus II	4
MTH 181	Discrete Structures I	3
MTH 182	Discrete Structures II	3
MTH 331	Probability	3

4.
Complete the following Science/Quantitative courses:

PHY 113	Classical Physics I	4
PHY 114	Classical Physics II	4
CIS 362	Empirical Methods for Computer Science	3
	Science/Quantitative course	3

5.
Complete the General Education requirements:

Writing, Tier 1 and Tier 2; Information, Tier 1		
ENL 101	Critical Writing and Reading I	3
ENL 102	Critical Writing and Reading II	3
ENL 266	Technical Communications	3
Ethics and Cultural Responsibility		
CIS 381	Social and Ethical Aspects of Computing	3
Cultural and Artistic Literacy		9
Global Awareness		3
Diversity		3

6.

Complete 9 hours of free electives	9
Program Total	**at least 120**

Computer Science Minors

Students interested in a minor should contact the CIS department for an application and admission requirements. The department offers three different minors, each with the emphasis indicated. Each requires credits as specified below.

Admission to one of the minors

Students must meet the university's admission requirements for a minor, which include having completed 54 credits. For computer science, prospective minors are encouraged to inquire and plan their minor program prior to earning 54 credits, because the structure of requirements could necessitate the use of more than four semesters. Courses completed prior to formal declaration will count toward the minor program.

Admission to the minor is accomplished through an application form available in the office of the chairperson of the department accompanied by current transcript(s). Upon acceptance the student is assigned an advisor, who works with the student to design an individual minor program that meets the stated requirements. Study plans are to be approved by the department chairperson.

Computer Science

Objectives

1. To develop in the student an understanding of computer science as a discipline, its structure, methodologies, and trends.
2. To use the computer as a tool to solve problems.
3. To give the student a sufficient background in computer science to continue his/her study of the discipline independently.
4. To give students a sufficient knowledge in computer science to gain an advantage when entering the current job market.

Requirements

Complete the following courses with a grade of C or better:

		credits
CIS 180	Object-Oriented Programming	4
CIS 181	Programming Paradigms	4
CIS 280	Software Specif. & Design	4
CIS 360	Algorithms & Data Structures	3
CIS 361	Models of Computation	3
CIS	One additional 300/400 course	3
	Total	21

Students with prior experience in programming can substitute CIS 183 Object Paradigm for the sequence of courses CIS 180/181. Students can substitute the sequence CIS 115 Computer Programming in C / CIS 215 Program Design and Data Structures for the sequence CIS 180 / 181.

Software Engineering

Objectives

1. To develop in the student the ability to use software development methodologies and software processes to participate in the design and implementation of software systems.
2. To teach the student how to design and implement software.
3. To give the student a sufficient background in software engineering to continue his/her study of the discipline independently.
4. To give students a sufficient knowledge in software engineering to gain an advantage when entering the current job market.

Requirements

Complete the following courses with a grade of C or better:

		credits
CIS 180	Object-Oriented Programming	4
CIS 181	Programming Paradigms	4
CIS 280	Software Specif. & Design	4
CIS 480	Software Engineering	4
CIS 481	Parallel & Distr. Softw. Systems	3
CIS	One additional 300/400 course	3
	Total	22

CIS 480 has as a prerequisite CIS 362 Empirical Methods. Students without a knowledge of empirical methods equivalent to CIS 362 must take that prerequisite course.

Students with prior experience in programming can substitute CIS 183 Object Paradigm for the sequence of courses CIS 180/181.

System Software

Objectives

1. To develop in the student the ability to use computer systems and system software and participate in the design and implementation of operating systems and computer networks.
2. To give the student a sufficient background in systems software to continue his/her study of the discipline independently.
3. To give students a sufficient knowledge in operating software and computer networks to gain an advantage when entering the current job market.

Requirements

Complete the following courses with a grade of C or better:

		credits
CIS 115	Computer Programming with C	3
CIS 215	Program Design/Data Str. w/ C	3
CIS 272	Intro. to Computing Systems	4
CIS 273	Computer Organization and design	4
CIS 370	Design of Operating Systems	4
CIS 475	Computer Networks	3
CIS	One additional 300/400 course	3
	Total	24

Gen Ed note: Computer Science courses satisfy the Natural Science and Technology requirement.

Computer and Information Science Courses

CIS 110 three credits
Computer Literacy
An introduction to computers, evolution of computer systems and the impact of computers on the society. In this hands-on laboratory course, students will use Macintosh computers to learn about components of computer systems and study various applications including word processing, spreadsheet, database, presentation and internet browsing software. With the HyperCard, students will learn how to design and program in the multimedia environment. Each student will then use this knowledge to develop an individual final project for the course.

CIS 115 three credits
Computer Programming with C
Algorithm development, syntax and semantics of a high level programming language, debugging and verification of programs. Concepts of structured programming. Arrays, subroutines. Elementary system concepts (compilation, time-sharing).

CIS 161 three credits
Computer Programming BASIC
An elementary programming course in the BASIC programming language, designed for the student with no prior experience in data processing.

CIS 120 three credits
Web Page Development
An introduction to the theory and application of creating web pages using HTML and JavaScript. HTML is the underlying structure used by the World Wide Web and will be used in this course along with JavaScript to assist students in building a foundation to become proficient in designing web pages. The primary theme of the course is learning how to create web pages that are attractive, meaningful, and well designed. Assessment of achieving these goals also will be addressed. As time allows, DHTML (Dynamic HTML), XML and Java applets may be used.

CIS 180 four credits
Object-Oriented Programming
3 hours lecture; 2 hours laboratory
Basic concepts in programming, and introduction to the object paradigm. The course introduces the concept of the object paradigm and teaches how to design and implement simple programs in an object-oriented language. The course also covers the basics of how to use a computer and basic software tools in the process of developing programs. The honors version of the course, in addition to the above contents, covers issues of human-computer interface design and the introduction to dynamic models in object-oriented software designs.

CIS 181 four credits
Programming Paradigms
3 hours lecture; 2 hours laboratory
Prerequisite: CIS 180
Software development using advanced object paradigm concepts; procedural paradigm; introduction to concurrency and fault tolerance. The course covers in depth the advanced topics of object paradigm such as inheritance polymorphism, and parametric polymorphism. These concepts are introduced in the context of developing software using software tools including the libraries of components. The procedural paradigm is introduced and compared with the object paradigm. The issues of programming with multiple processes, and programming of systems with exception handling capabilities are also addressed by this course.

CIS 183 four credits
Object-Oriented Paradigm
3 hours lecture; 2 hours laboratory
Introduction to the object paradigm. Software development using advanced object paradigm concepts of inheritance and polymorphism. Introduction to concurrency, and faulty tolerance. Developing software using software tools including the libraries of components. Comparison of procedural and object paradigms. Introduction to programming with multiple processes and with exception handling.

CIS 190 four credits
Introduction to Procedural Programming
3 hours lecture; 2 hours laboratory
Prerequisite: CIS major
Procedural Programming (C/C++) under Unix. Data types, variable declarations, arithmetic expressions, conditional statements, macros, function prototypes, standard libraries, file processing, pointers, structures, unions, and dynamic memory management are discussed. Unix file system, shell scripts, input/output redirection, piping, programming with standard I/O, and unix system calls are covered.

CIS 215 three credits
Program Design and Data Structures With C
Prerequisite: CIS 115
Program design issues, abstract data types, procedural and data abstraction issues. The following data structures are explored: linked lists, stacks, queues, binary trees, tables. Procedural abstractions such as: functions, recursive functions with variable number of parameters, are further discussed. Features of the C programming language such as: preprocessor, macros, standard libraries, and programs with files are discussed.

CIS 261 three credits
Computer Programming, FORTRAN
An intensive course in the FORTRAN programming language.

CIS 265 three credits
Program Design and Data Structures with C
Prerequisite: Any Programming Course
An intensive course in the "C" programming language with introduction to UNIX for students who are already proficient in another high-level programming language such as BASIC, FORTRAN, or PASCAL.

CIS 266 three credits
Object-Oriented Programming in C++
Prerequisite: Any programming course
Fundamental conceptual tools and their implementation of object-oriented design and programming such as: object, type, class, implementation hiding, inheritance, parametric typing, function overloading, polymorphism, source code reusability, and object code reusability. Object-Oriented Analysis/Design for problem solving. Implementation of Object-Oriented Programming paradigm is illustrated by program development in C++.

CIS 272 four credits
Introduction to Computing Systems
3 hours lecture; 2 hours laboratory
Prerequisite: CIS 190
Corequisite: MTH 181
Introduction to major components of computer system software. The course introduces fundamental concepts of computing systems, such as binary arithmetic and data representation, the Von Neumann model for processing computer programs, the operation of memory, instruction set, and machine and assembly language programming. It systematically presents the levels of transformations from machine language to assembly language to high level language. The role of such systems software components as assemblers, compilers, linkers, loaders, and operating systems is studied. The course has a strong project component.

CIS 273 four credits

Computer Organization and Design
3 hours lecture; 2 hours laboratory
Prerequisite: CIS 190
Corequisite: MTH 181
Laws of computer organization and design for RISC architectures. Interfaces between hardware and software are studied. Influence of instruction set on performance is presented. Design of a processor with pipelining is analyzed. Computer arithmetic is studied. Memory hierarchy and their influence on performance is documented. Elements of interfacing and I/O organization are included. The course has a design, implementation, and analytical components. (Formerly offered as CIS 270)

CIS 280 four credits
Software Specification and Design
3 hours lecture; 2 hours laboratory
Prerequisite: CIS 272
Object-oriented analysis and design: methodologies and tools. The course focuses on methodologies of specification and design of software systems. It addresses the issues of user interface design and software prototyping. The course also presents the state of the art in the tool and environments supporting the front end of the software development cycle.

CIS 298 one to six credits
Experiential Learning
Prerequisites: At least sophomore standing; permission of the instructor, department chairperson, and college dean
Work experience at an elective level supervised for academic credit by a faculty member in an appropriate academic field. Conditions and hours to be arranged. Graded CR/NC. For specific procedures and regulations, see section of catalogue on Other Learning Experiences.

CIS 314 four credits
Computer Architecture
Prerequisite: CIS 273, 360
General organization of a computer system. Memory hierarchy. Emphasis on memory organization and management implementation. Local and long distance communication, bus, input-output organization and control. Programmed I/O and I/O processors. Interrupt handling. Processor organization; instruction set; arithmetic-logic unit; parallel and stack processors. Programmed and hardwired, central and distributed control.

CIS 360 three credits
Algorithms and Data Structures
Prerequisite: CIS 181
Comprehensive coverage of all major groups of algorithms, including divide-and-conquer, dynamic programming, greedy, backtracking, branch-and-bound, and parallel algorithms. Discussion of the design and implementation of complex, dynamic data structures. The course also covers an introduction to the functional paradigm.

CIS 361 three credits
Models of Computation
Prerequisites: CIS 181, MTH 182
Models of sequential, parallel, and distributed computations. The Chomsky hierarchy of formal languages and their accepting machines are studied in detail. The relationship of these languages and machines to computer programs is presented. Influence of a Turing machine and related formalisms on modern computing are studied. Decidability of decision problems is explained. Several models of parallel and distributed computations are introduced and compared.

CIS 362 three credits
Empirical Methods for Computer Science
Prerequisite: MTH 331
Topics and methods supporting an experimental approach to the study of issues in computer science and software engineering. Course covers the basic principles of experimental design and case study construction. Emphasis in the course is on the use of empirical methods for decision making and the evaluation of research in computer science and software engineering that employ empirical methods.

CIS 370 four credits
Design of Operating Systems
3 hours lecture; 2 hours laboratory
Prerequisite: CIS 273
Principles of modern operating systems and their design. Scientific principles and engineering rules of operating systems are explored. Process and storage management subsystems are analyzed in detail. Protection and security are taken into account in design. An introduction to distributed operating systems is also presented. This is a design and project based course with a laboratory component.

CIS 381 three credits **E**
Social and Ethical Aspects of Computing
Prerequisite: Junior standing
Introduction to the social, legal, and ethical issues of computing. Topics include how computer use affects social and work relationships and the uses of computers in society. These will be reviewed in the context of risks, privacy and intrusion, computer crime, intellectual property, and professional decision-making. Students analyze scenarios that allow them to view ethical decision-making as a crucial part of understanding the world of computing.

CIS 410 three credits
Programming Language Design
Prerequisite: CIS 360
Fundamental concepts and general principles underlying current programming languages and models. Topics include control and data abstractions, language processing and binding, the relationship between language design and language implementation. A variety of computational paradigms are discussed: functional programming, logic programming, object-oriented programming, and procedural programming.

CIS 411 three credits
Seminar
Prerequisite: Senior CIS standing
Advanced topics in Computer Science.

CIS 412 three credits
Artificial Intelligence
Prerequisite: CIS 360 or permission of instructor
Artificial intelligence problem-solving paradigms. The course covers heuristic versus algorithmic methods, rational and heuristic approaches, and description of cognitive processes; and objectives of work in artificial intelligence, the mid-brain problem and nature of intelligence, simulation of cognitive behavior, and self-organizing systems. Examples are given of representative applications.

CIS 421 three credits
Introduction to the Theory of Computing
3 hours lecture
Prerequisite: CIS 361
Several of the most significant models of computation will be reviewed, i.e., Turing machines, 1-calculus, predicate calculus. The traditional undecidibility results will be covered, along with the attempts to overcome the resulting limitations in restricted situations. Mechanical theorem provers will be considered. The resolution and unification predicate calculus methods will be discussed along with appropriate PROLOG programming assignments. The Boyer-Moore approach will be discussed, along with LISP programming assignments.

CIS 422 four credits
Design of Parallel Algorithms

3 hours lecture, 2 hours laboratory
Prerequisite: CIS 360 or permission of instructor
Design and analysis of algorithms for parallel computers with two modes of operation: shared memory, and message passing. Synchronous and asynchronous parallel algorithms for the following problems will be designed and implemented: selection, merging, sorting, searching, generating permutations and combinations, and matrix operations. Parallel computational complexity of these algorithms will be analyzed.

CIS 430 three credits
Data Mining and Knowledge Discovery
Prerequisite: CIS 360
Designed to provide students with a solid background in data mining and knowledge discovery concepts, tools, and methodology, as well as their applicability to real world problems. A variety of data mining techniques will be explored including memory-based reasoning, cluster detection, classification, neural networks, and finding understandable knowledge in large sets of real world examples. Some related topics such as web and multimedia mining will be discussed. Students will gain hands-on experience in data mining techniques using various data mining software packages and tools.

CIS 431 four credits
Human-Computer Interaction
3 hours lecture; 3 hours laboratory
Prerequisite: CIS 362 or permission of instructor
Theory and principles for constructing usable software systems. Cognitive and effective aspects of users. The impact of user characteristics on design decisions. The construction and evaluation of the user interface. Sensory and perceptual aspects of interfaces, task structure, input modalities, screen layout, and user documentation. Individual concerns for systems such as personal productivity tools, real-time control systems, instructional software, and games.

CIS 443 three credits
Process-Based Design
Prerequisite: CIS 480 or permission of instructor
Design of systems composed of multiple, communicating processes (tasks), including distributed systems and real-time systems. Programming with ADA.

CIS 452 three credits
Database Systems
Prerequisite: CIS 280
Use of DBMS software in the development of an information system. Overview of the ANSI/SPARC Study Group on Database Management Systems model. Relational database model techniques. Emphasis on user views necessary to support data management and retrieval.

CIS 454 three credits
Computer Graphics
Prerequisite: At least junior CIS standing
Graphics devices. Two dimensional and three dimensional image representations and transformations. Graphics systems software architecture; graphics standards; packages.

CIS 465 three credits
Topics in Computer Vision
Prerequisite: CIS 360 or permission of the instructor
Foundations of computer vision. Image formats, projection models, regions, filters, edge detection, segmentation, shape description and representation, object recognition and understanding, and stereo-vision are discussed.

CIS 467 three credits
Image Analysis and Processing
Prerequisite: CIS 360 or permission of the instructor
Fundamentals in image analysis and processing. Topics in image processing such as display and filtering, image restoration, segmentation, compression of image information, warping, morphological processing of images, wavelets, multi-resolution imaging and unitary transforms are discussed.

CIS 471 three credits
Compiler Design
Prerequisite: CIS 361
Organization of a compiler including lexical and syntax analysis, symbol tables, object code generation, error detection and recovery, code optimization techniques, and overall design. Compilation techniques and run-time structures in block-structured language.

CIS 475 three credits
Computer Networks
Prerequisites: CIS 370
Topology of computer networks. Physical transmission. Error handling. Protocols. Satellite, packet radio, and local networks. Network interconnection. Security. Applications of computer networks.

CIS 476 three credits
Network Programming
Prerequisite: CIS 370
Introduction to computer networks, and methods for programming network services and applications. The course covers the Internet protocol suite (e.g. IP, TCP, UDP), socket programming, and client-server design (e.g. connectionless, connection oriented, multiprotocol). The course discusses the implementation of real-time applications (e.g. streaming audio and video), and application - level gateways and tunneling. In addition, the course addresses protocol implementation using routing sockets and raw sockets. Programming projects represent a significant component of the course.

CIS 480 four credits
Software Engineering
3 hours lecture; 2 hours laboratory
Prerequisite: CIS 280, 362
Software engineering models and processes; total quality management. The course will address the technical, logistical, and social issues associated with the software development process. It will cover the issues of total quality management at the team and enterprise levels.

CIS 481 three credits
Parallel and Distributed Software Systems
Prerequisite: CIS 280, 370
Parallelism and distribution of processing; software bus concept; patterns in software design. The course provides an in-depth discussion of the software systems wit multiple processes and of the relationship between concurrency and distribution of processes. The concept of the software bus, the existing standards, and the issues associated with their implementation are covered.

CIS 490 three credits
Machine Learning
Prerequisite: CIS 360
Constructing computer programs that automatically improve with experience is the main task of machine learning. The key algorithms in the area are presented. Learning concepts as decision trees, artificial neural networks and Bayesian approach are discussed. The standard iterative dichotomizer (ID3) is presented, the issues of overfitting, attribute selection and handling missing data are discussed. Neural nets are discussed in detail, examples of supervised and unsupervised learning are presented. Instance-based learning, i.e. k-nearest neighbor learning, case-based reasoning are introduced. Genetic algorithms are discussed

Note: Some graduate courses may be open to undergraduates. Please consult your department chairperson. See the *Graduate Catalogue* for graduate general and program requirements.

on introductory level.

CIS 491, 492 three credits each
Honors Project I, II
Prerequisites: Junior standing, eligible for department honors program
The project courses required for completion of the departmental honors program. A significant experience in developing a computer system (typically), but equivalent alternatives are allowed. This system should require an extensive design effort prior to implementation and a serious effort for this implementation. It should have scholarly and/or practical value and might well profit by being interdisciplinary in nature.

CIS 495 variable credit
Independent Study
Prerequisites: Upper-division standing; permission of instructor, department chairperson, and college dean
Study under the supervision of a faculty member in an area not otherwise part of the discipline's course offerings. Conditions and hours to be arranged.

CIS 196, 296, 396, 496 three credits
Directed Study
Prerequisites: Permission of the instructor, department chairperson, and college dean
Study under the supervision of a faculty member in an area covered in a regular course not currently being offered. Conditions and hours to be arranged.

Graduate Courses in Computer Science

CIS 521 three credits
Computability Theory
Prerequisite: CIS 361 or permission of instructor
Computability of sets and functions in terms of various computation models, Church-Turing thesis. Systems of recursion equations and Post canonical systems are studied. Properties of the classes of recursive functions, recursive sets, and recursively enumerable sets are also covered.

CIS 522 three credits
Algorithms and Complexity
Prerequisite: CIS 360 or permission of instructor
Evaluation of algorithms concerning their time and space complexity. Complexity hierarchies, axiomatic approach to computational complexity, NP complete problems, approximation algorithms for these problems.

CIS 525 three credits
Parallel and Distributed Software Development
Prerequisite: CIS 361 or permission of instructor
Design and development of parallel and distributed systems. This course provides state-of-the art presentation of software development for parallel and distributed systems. A systematic model-based approach has been applied across stages of software development. Various versions of Petri nets are used to model , specify, validate, and verify correctness of parallel and distributed systems. Performance is also assessed based on stochastic Petri nets. Rapid prototyping of parallel and distributed systems with automatic code generation is an ultimate goal of his course. Comparison with other approaches is also provided.

CIS 526 three credits
Functional Programming and Type Theory
Prerequisite: CIS 360 or permission of instructor
Introduction to logic, type theory, and the lambda calculus. The course examines LISP as a first application of these ideas, consistency proofs using cut elimination and type theory, and constructive type of theory in functional programming languages in attempts to achieve program verification and automatic code generation.

CIS 531 three credits
Software System Specification
Prerequisite: CIS 480 or equivalent
Formal foundation of the theory and practice of software specification; production of correct, consistent, and reliable software systems by expressing the requirements of the system in formal ways. Formal and informal requirements analysis and specification techniques, the relation of analysis and specification to concerns of validation and verification, maintenance, and reusability.

CIS 532 three credits
Software Systems Design
Prerequisite: CIS 480 or equivalent
Principles and techniques for obtaining an architectural design from a system specification. Where appropriate, automated software design tools are used to demonstrate particular methodology. The relation of various design methods to the production of quality software that meets its specification, and the relation of design method to other life-cycle aspects. Design methods, design tools, the design process, and particular application domains for design techniques.

CIS 543 three credits
Software Systems Design with ADA
Prerequisite: CIS 443 or permission of instructor
Software engineering principles and methodologies. Also considered are issues related to the life cycle of large systems developed in ADA, software engineering of real-time, fault-tolerant and distributed systems, and software reuse.

CIS 545 three credits
Programming Languages
Prerequisite: Permission of instructor
Techniques of formal definition of programming languages, semantics of programming languages, programming styles, and language effects on software production. Introduces current trends in programming such as language features of problem-oriented and object-oriented programming, and analysis and design of user-oriented application languages.

CIS 552 three credits
Database Design
Prerequisite: CIS 452 or permission of instructor
The relational, hierarchical, and network approaches to database systems, including relational algebra and calculus, data dependencies, normal forms, data semantics, query optimization, and concurrency control on distributed database systems.

CIS 554 three credits
Advanced Computer Graphics
Prerequisite: CIS 454 or permission of instructor
Three-dimensional graphics including: color, shading, shadowing and texture, hidden surface algorithms. An extensive project will be assigned, including documentation and presentation.

CIS 560 three credits
Theoretical Computer Science
Prerequisites: CIS 360, 361, or equivalents
Theoretical basis of the development of computer science. The course details particular formalisms used in the design of hardware and software systems. Intrinsic limitations of computation are described. Advanced topics of automata theory and analysis of algorithms are included. The course also covers Turing machines, the halting problem, models of computation, intractable computations, polynomial reductions, P vs. NP, parallel algorithms, various formal descriptions and specifications of programs and computations, and proofs of program correctness and interactive proof systems.

CIS 561 three credits
Artificial Intelligence
Expert system architectures: forward-production, logic programming, deductive retrieval, and semantic network systems. The course also treats natural language systems, illustrative working systems, and AI programming.

CIS 564 three credits
Mobile Robotics
Prerequisite: Graduate standing
The theory, software and hardware for autonomous mobile robots. Reactive behavior-based, deliberative goal-based, and utility-based robotic architectures will be presented. Control and planning under bounded resources will be covered. Interaction with environment using sensors and actuators, robot kinematics and dynamics, reinforcement and evolutionary learning techniques for intelligent robots, interaction of competing and cooperating multi-robot systems will be presented. Various applications of mobile robots will be explored.

CIS 565 three credits
Evolutionary Computation
Prerequisite: Graduate standing
Presentation of evolutionary algorithms and comparison to traditional solving techniques. This course deals with a powerful new technique for solution of hard, intractable real-world problems, based on principles of natural evolution. Four main areas of evolutionary computation will be explored: genetic algorithms, genetic programming, evolution strategies, and evolutionary programming. Applications of evolutionary computation to related areas of computer science will be discussed.

CIS 566 three credits
Theory of Linear and Integer Programming and Computer Applications
Prerequisite: CIS 360 or permission of instructor
Basics of the simplex algorithm, tableaux, artificial variables, the two-phase method, the dual problem and its economic interpretation, primal-dual relationships and method. Also studied are applications to transportation problems and network flows, the polynomial methods of Khachiyan and Karmarkar, and integer programming. Computer methods and exercises will be employed throughout.

CIS 570 three credits
Advanced Computer Systems
Prerequisite: CIS 314 or equivalent
In depth treatment of current computer systems, with performance issues at the center of an analytical approach. The course explores operating system software and the interrelation between architecture and system software. Advanced topics of compiling, assembly, linking and loading of high-level language software are included. The course treats mechanisms of IO and the memory hierarchy, various features of traditional machines, advanced features of modern machines such as RISC and multi-processor machines, and file systems and networked and distributed systems such as inter- and intra-nets. Throughout, performance issues are at the center of an analytical approach.

CIS 571 three credits
Compiler Construction
Prerequisite: CIS 471 or permission of instructor
Different techniques for lexical analysis, syntax analysis, and object code generation. Emphasis on code optimization techniques and compiler-construction tools. The course will include a significant project.

CIS 572 three credits
Real Time Systems
Prerequisite: CIS 481 or permission of instructor
Design and implementation of real-time systems. Implementation of real-time system in ADA, scheduling, fault tolerance, and distributed real-time systems are also studied.

CIS 573 three credits
Operating Systems
Prerequisite: CIS 370 or permission of instructor
The methodologies of operating systems design and implementation. Concurrency, synchronization, process communication, switching control, deadlocks, implementation of dynamic structures, design of operating systems modules and interfaces, system security and integrity, and system updating and documentation are also studied.

CIS 574 three credits
Advanced Computer Architectures
Prerequisite: CIS 314 or permission of instructor
Study of recent advances in computer organization. Parallel processors, pipelined processors, modular and network architectures data-flow machines, fault-tolerant systems, language-directed, object-based, capability-based, and message-based processor organizations.

CIS 575 three credits
Parallel Algorithms and Parallel Architectures
Prerequisites: CIS 314, 360; or permission of instructor
Parallel algorithms and their implementations in parallel architectures. In the first part of the course parallel algorithms are analyzed for problems in graph theory, algebra, FFT, and artificial intelligence. The second part presents implementations of these algorithms in various parallel architectures.

CIS 577 three credits
Computer Networks
Prerequisite: CIS 475 or permission of instructor
Analysis and modeling of centralized and distributed computer networks. Queuing network analysis, principles of network design, software considerations, and design of computer networks are also studied.

CIS 578 three credits
Evaluation of Computer Systems Performance
Prerequisite: MTH 331, CIS 314; or permission of instructor.
Techniques of analysis and simulation for evaluation of computer systems performance. Queuing systems, Poisson processes, scheduling, service distribution, conservation laws, queuing networks, and discrete

simulations are also studied.

CIS 580 three credits
Paradigmatic Software Development
Prerequisite: CIS 311 or equivalent
Software development in the context of various paradigms. The strategies and methods of the procedural, object-oriented, and functional paradigms are studied and practiced. The modeling of software processes will be considered from both the process and product views, as will the appropriateness and measures of effectiveness of these processes in the design of software systems. Students will apply these measures to the course exercises, determining and reviewing the impact of these methods on individual design.

CIS 581 three credits
Design and Verification of Information Systems
Prerequisite: CIS 580 or permission of instructor
Sound design methodologies and technologies in development and maintenance of information systems/business systems with special emphasis on workflow management systems. An applied course that emphasizes the formal approach, this course also addresses issues of adaptability and flexibility of information systems and their evaluation. The course supports concurrent execution of information systems during the design stage and adopts and applies various forms of Petri nets.

CIS 585 three credits
Image Processing and Machine Vision
Prerequisite: Graduate standing and permission of the instructor
Foundations of image processing and machine vision. Students apply and evaluate topics such as edge detection, segmentation, shape representation, and object recognition. Stereo vision and motion analysis will be covered in detail including calibration, range images, change detection, motion correspondence, and 2-D and 3-D tracking. Important research papers will be discussed in class.

CIS 588 three credits
Neural Computing
Prerequisite: Any course in programming languages and data structures
Fundamentals of artificial neural networks including application needs for neural networks, discussing the various architectures, learning algorithms and examples of applications. The standard neural networks are discussed in greater details, which allows for branching of architectures and combining of strategies for growing and/or constructing neural networks.

CIS 595 three credits
Independent Study
Prerequisites: Upper-division standing; permission of instructor, graduate director, and college dean
Study under the supervision of a faculty member in an area not otherwise part of the discipline's course offerings. Conditions and hours to be arranged.

CIS 596 three credits
Directed Study
Prerequisites: Permission of the instructor, graduate director, and college dean
Study under the supervision of a faculty member in an area covered in a regular course not currently being offered. Conditions and hours to be arranged.

CIS 600 three credits
Master's Project
Prerequisites: CIS 560, 570, and 580
Provides an experience in the development of a detailed, significant project in computer science under the close supervision of a faculty member, perhaps as one member of a student team. This project may be a software implementation, a design effort, or a theoretical or practical written analysis. Public presentation of the master's project and evaluation by two faculty other than the project supervisor are required.

CIS 601, 602, 603 three credits each
Special Topics
Offered as needed to present advanced material to graduate students.

CIS 690 three credits
Master's Thesis
Prerequisite: Permission of the Graduate Program Committee, based on performance in CIS 600, approval of proposed topic, and support of a faculty advisor and two faculty readers.
Research leading to submission of a formal thesis. This course provides an optional thesis experience, which may be based on the student's Project in a more intense form or be a sequel effort of a different character. In exceptional circumstances, the student may earn up to six thesis credits, if approved by the Graduate Program Committee. Graded A-F.