# COMPUTING AND INFORMATION SCIENCE

## FACULTY OF COMPUTING AND INFORMATION SCIENCE

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## INTRODUCTION

Computing and Information Science (CIS) offers courses and programs campuswide in various academic disciplines in which computing is integral. It is home to the Department of Computer Science and interdisciplinary programs in computational biology, computational science and engineering, digital arts and graphics, and information science. The faculty associated with CIS programs hold joint appointments with CIS and another Cornell academic unit.

Computing and Information Science is a rapidly changing area. Please consult the CIS web site, www.cis.cornell.edu/, for the most current news of programs and courses, or visit the CIS undergraduate office in 303 Upson Hall.

## ACADEMIC PROGRAMS

Computing and Information Science offers the following academic programs through their corresponding colleges. See the departmental listings for details of the programs.

### Computational Biology

The program of study in computational biology is part of the biological sciences major offered through the College of Agriculture and Life Sciences and the College of Arts and Sciences and is coordinated by the Office of Undergraduate Biology. It provides core training in biology and the supporting physical and information sciences. It is designed for students who want to emphasize basic biological science.

The concentration in computational molecular biology is offered by the Department of Computer Science to students enrolled in the College of Arts and Sciences and the College of Engineering. It provides core training in computer science and biology. It is designed for students who want to emphasize computational science.

### Computational Science and Engineering

Computational science and engineering is an emerging CIS program. Numerous courses are taught throughout the university. Topics include numerical methods, modeling and simulation, and real-time computing and control. CIS sponsors several "tool-based" short courses for students who anticipate that their studies will have a strong computational component (CIS 401, 402, 403, 404). A course on data structures for computational science (CIS 409) is also offered.

### Computer Science

All CIS programs have connections to computer science, the study of computation in all of its forms. The curriculum covers the theory of algorithms and computing and its many applications in science, engineering, and business. Students learn the algorithmic method of thinking and how to bring it to bear on a wide range of problems. They also study the elements of computing and information technology such as system design, problem specification, programming, system analysis and evaluation, and complex modeling. Research areas include programming languages, compilers, computing systems, artificial intelligence, natural language processing, computer graphics, computer vision, databases, networks, bioinformatics, the theory of algorithms, scientific computing, and computational logic.

The Department of Computer Science offers the computer science major to students in the College of Arts and Sciences and the College of Engineering, the computer science minor to students in the College of Engineering, and the master of engineering (M.Eng.) degree in computer science to students in the College of Engineering.

### Digital Arts and Graphics

CIS is working to develop undergraduate and graduate research programs and curricula in the digital arts and graphics. Several courses already exist in this area (ART 372, ART 391, CIS 165, COM S 465, 467, 468, MUSIC 120). More courses in this growing field are planned for the near future.

### Information Science

Information science at Cornell is an interdisciplinary program that studies the design and use of information systems in a social context. It integrates the study of three aspects of digital information systems. First, information science studies computing systems that provide people with information content; this study overlaps with parts of computer science, stressing the design, construction, and use of large information systems such as the

World Wide Web and other global information resources. The second aspect of information science examines how people engage these information resources and how they can be integrated into everyday life. This area is also called "human-centered systems" because it is concerned with systems that hundreds of millions of people will use in daily life. The third aspect deals with understanding how information systems are situated in social, economic, and historical contexts. It explores the economic value of information, the legal constraints on systems, their social impact, and the cultural aspects of their construction. These are synergistic topics, and the next generation of scientists, scholars, business leaders, and government workers will need to understand them and how they relate.

Specific topics emphasized in the information science program include information networks; information discovery; knowledge organization; interaction design; interface design and evaluation; collaboration within and across groups, communities, organizations, and society; computational linguistics; computational techniques in the collection, archiving, and analysis of social science data; information privacy; methods of collecting, preserving, and distributing information; information system design; cognition and learning; social informatics; and cultural studies of computation.

The information science (IS) major is offered by the College of Agriculture and Life Sciences and the College of Arts and Sciences. Students in the College of Engineering may major in information science, systems, and technology (ISST), which is offered jointly by the Department of Computer Science and the School of Operations Research and Industrial Engineering. For details about the IS and ISST majors, please refer to the respective colleges.

The minor/concentration in information science is available to students in all undergraduate colleges.

## THE INFORMATION SCIENCE CONCENTRATION/MINOR

A concentration/minor in information science is available to students in the Colleges of Agriculture and Life Sciences (CALS); Architecture, Art, and Planning (AAP; available to Architecture, Art, and Planning students); Arts and Sciences; Engineering; and Human Ecology; and the Schools of Hotel Administration and Industrial and Labor Relations (ILR). Because of small differences in regulations between the colleges, there are sometimes slight variations in the requirements, depending on a student's college and, in a few cases, a student's major. All students interested in pursuing the information science concentration/minor must initiate the process by sending an e-mail message with their name, college, year of study (e.g., second-semester sophomore), expected graduation date, and (intended) major to infosci-minor@cs.cornell.edu. Students are also referred to www.infosci.cornell.edu/ugrad/concentration.html for the most up-to-date description of the concentration and its requirements.

Information science is an interdisciplinary field covering all aspects of digital information. The program has three main areas: human-centered systems, social systems, and information systems. Human-centered systems studies the relationship between humans and information, drawing from human-computer interaction and cognitive science. Social systems examines information in its economic, legal, political, cultural, and social contexts. Information systems studies the computer science problems of representing, storing, manipulating, and using digital information.

The concentration/minor has been designed to ensure that students have substantial grounding in all three of these areas. To this end, the requirements for the undergraduate concentration/minor are as follows. All courses must be chosen from the course lists below. In addition, a letter grade of C or better is required; S-U courses are not allowed.

- **Statistics:** one course.
- **Human-centered systems** (human-computer interaction and cognitive science): two courses (for all colleges except Engineering); one course (Engineering).
- **Social systems** (social, economic, political, cultural, and legal issues): one course.
- **Information systems** (primarily computer science): two courses.
- **Elective:** one additional course from any component area. (Engineering students and all Computer science majors must select a course from human-centered systems or social systems. Communication majors must select a course outside Communication. Students in other majors should check with their advisers to make sure there are no special departmental restrictions or requirements.)

### Statistics

An introductory course that provides a working knowledge of basic probability and statistics and their application to analyzing data occurring in the real world.

Engineering students must take one of the following:

- ENGRD 270 Basic Engineering Probability and Statistics
- CEE 304 Uncertainty Analysis in Engineering
- ECE 310 Introduction to Probability and Random Signals

All other students can meet this requirement with any one of the following:

- MATH 171 Statistical Theory and Application in the Real World
- H ADM 201 Operations Management
- PAM 210 Introduction to Statistics
- BTRY 261 Statistical Methods I (also STBTRY 261)
- ENGRD 270 Basic Engineering Probability and Statistics
- CIS 295 Mathematical Models for Information Science
- CEE 304 Uncertainty Analysis in Engineering
- ECE 310 Introduction to Probability and Random Signals
- ILRST 312 Applied Regression Methods
- ECON 319 Introduction to Statistics and Probability
- PSYCH 350 Statistics and Research Design or equivalent with permission of the Information Science undergraduate program director (send mail to infosci-minor@cs.cornell.edu).

### Human-Centered Systems

- COGST 101 Introduction to Cognitive Science
- PSYCH 205 Perception
- INFO 214 Cognitive Psychology
- COMM 240 Communication and Information Technology
- INFO 245 Psychology of Social Computing
- PSYCH 280 Introduction to Social Psychology
- PSYCH 342 Human Perception: Applications to Computer Graphics, Art, and Visual Display
- INFO 345 Human-Computer Interaction Design
- PSYCH 347 Psychology of Visual Communications
- PSYCH 380 Social Cognition
- PSYCH 413 Information Processing: Conscious and Unconscious
- PSYCH 416 Modeling Perception and Cognition
- INFO 440 Advanced Human-Computer Interaction Design
- INFO 450 Language and Technology
- DEA 470 Applied Ergonomics Methods

### Social Systems

- STS 250 Technology in Society
- INFO 292 Inventing an Information Society
- ECON 301 Microeconomics*
- SOC 304 Social Networks and Social Processes
- ECON 313 Intermediate Microeconomic Theory*
- AEM 322 Technology, Information, and Business Strategy
- INFO 349 Media Technologies
- INFO 355 Computers: From Babbage to Gates
- ECON 368 Game Theory*
- INFO 387 The Automatic Lifestyle: Consumer Culture and Technology
- LAW 410 Limits on and Protection of Creative Expression—Copyright Law and Its Close Neighbors
- STS 411 Knowledge, Technology, and Property
- ECON 419 Economic Decisions Under Uncertainty
- COMM 428 Communication Law
- OR&IE 435 Introduction to Game Theory*
- STS 438 Minds, Machines, and Intelligence
- INFO 447 Social and Economic Data

- ECON 476/477 Decision Theory I and II
- INFO 515 Culture, Law, and Politics of the Internet

*Only one of ECON 301 and ECON 313 can be taken for IS credit. Only one of OR&IE 435 and ECON 368 can be taken for IS credit.

### Information Systems

- INFO 130 Introductory Design and Programming for the Web*
- COM S 211 Computers and Programming*
- INFO 230 Intermediate Design and Programming for the Web*
- INFO 330 Applied Database Systems
- LING 424 Computational Linguistics
- INFO 430 Information Retrieval
- INFO 431 Web Information Systems
- COM S 432 Introduction to Database Systems
- COM S 465 Computer Graphics I
- COM S 472 Foundations of Artificial Intelligence
- LING 474 Introduction to Natural Language Processing
- OR&IE 474 Statistical Data Mining
- COM S 478 Machine Learning
- OR&IE 480 Information Technology
- COM S 501 Software Engineering
- ECE 562 Fundamental Information Theory
- COM S 578 Empirical Methods in Machine Learning and Data Mining

*INFO 130 cannot be taken for information science credit by Engineering students. Computer science majors cannot use INFO 130 or INFO 230. COM S 211 cannot be taken for information science credit by majors for which it is a required course, e.g., Computer Science (COM S) and Operations Research and Industrial Engineering (OR&IE).

## COMPUTING AND INFORMATION SCIENCE (CIS) COURSES

**CIS 121 Introduction to MATLAB (also EAS 121)**
Fall, spring. 2 credits. Corequisite: MATH 111, 191, or equivalent.
An introduction to elementary computer programming concepts using MATLAB. Topics include problem analysis, development of algorithms, selection, iteration, functions, and arrays. Examples and assignments are chosen to build an appreciation for computational science. The goal is for each student to develop a facility with MATLAB that will be useful in other courses whenever there is a need for computer problem solving or visualization. The course assumes no programming experience.

**CIS 122 Application of FORTRAN in the Earth and Environmental Sciences (also EAS 150)**
Spring. 2 credits. Prerequisite: CIS/EAS 121 or equivalent.
For description, see EAS 150.

**CIS 165 Computing in the Arts (also COM S 165, MUSIC 165)**
Fall. 3 credits.
Over the centuries, artists in a wide variety of media have employed many approaches to the creative process, ranging from the philosophical to the mechanical to the virtual. This course unravels some of the mysteries going on inside software used for art and music. We look at ways of breaking things apart and sampling and ways of putting things together and resynthesising, and we explore ideas for creation. There are no formal course prerequisites (in particular, no courses in programming, calculus, or probability), although a good comfort level with computers and some of the arts is helpful. This course does not teach software packages for creating art and music. The course complements ART 171+ and MUSIC 120+.

**CIS 167 Visual Imaging in the Electronic Age (also COMS S 167, ENGRI 167)**
Spring. 3 credits. S-U grades optional.
The concepts and ideas behind computer imaging and computer graphics, both software and hardware. Topics include perspective representations, display technology, how television works, bandwidth concepts, digital photography, computer graphics modeling and rendering, matting and compositing, color perception, data acquisition, and volumetric imaging. Historical precedents, primarily from the art world, are used throughout. Other modes of imaging are discussed, including laser scanning, ultrasound, x-rays, and magnetic resonance, each of which is important to medical practice. This is not a course on how to use any particular graphics/imaging program, but rather an explanation of the underlying principles.

**CIS 191 Media Arts Studio I (also ART 391, THETR 391)**
Fall. 3 credits. Prerequisite: one of the following courses: ART 171, THETR 277, 377, MUSIC 120, or equivalent; must be a junior and have permission of the instructor. Lab fee $50.
For description, see ART 391.

**CIS 300 Introduction to Computer Game Design**
Fall. 4 credits. Prerequisites: for artists, ART 251 and experience with Photoshop and Illustrator or similar software; for musicians, COM S 100, COM S/INFO 130, MUSIC 120; for programmers, COM S/ENGRD 211, COM S 213, or equivalent experience in C++, CIS 409; for writers, COM S 100, COM S/INFO 130, ENGL 280/281.
This course investigates the theory and practice of developing computer games from a blend of technical, aesthetic, and cultural perspectives. Technical aspects of game architecture include software engineering, artificial intelligence, game physics, computer graphics, and networking. Aesthetic and cultural aspects of design include art and modeling, sound and music, history of games, genre analysis, role of violence, gender issues in games, game balance, and careers in the industry. Programmers, artists, musicians, and writers collaborate to produce an original computer game.

**CIS 401 Introduction to Applied Scientific Computing with MATLAB**
Fall. 1 credit. Usually weeks 2–5. Prerequisite: COM S 100 or equivalent programming experience. S-U grades only.
An introduction to the use of MATLAB as an aid to scientific research. The course introduces the basic syntax and features of MATLAB and develops the background necessary for the more specialized courses. The course covers basic MATLAB programming and vectorized operations, data input/output, and simple visualization. The course emphasizes applied issues such as managing large data sets, simulation, and visualization but also introduces fundamental ideas in scientific computing such as floating point arithmetic and algorithm efficiency. Although the course uses MATLAB, the ideas and concepts covered are common to many computational environments.

**CIS 402 Scientific Visualization with MATLAB**
Fall. 1 credit. Usually weeks 6–10. Prerequisites: COM S 100 or equivalent programming experience; COM S 401/CIS 401 recommended but not required. S-U grades only.
A survey of the advanced visualization features in MATLAB. The course covers MATLAB's "handle graphics" paradigm, specialized graphics routines for vectors and fields, and introduces color mapping, lighting, and new features for controlling object transparency. Although the course is meant to introduce students to the capabilities of the MATLAB system, it also emphasizes the basic goal of visualization: producing an image that effectively communicates a scientific result.

**[CIS 403 Development of Scientific Computing Programs**
Spring. 1 credit. Usually weeks 1–4. Prerequisite: COM S 100 or equivalent programming experience. S-U grades only.
This course is designed for graduate students who, in their research, will develop computer programs to solve scientific or engineering problems (e.g., in Fortran, C, or Java). Approaches and tools are presented that facilitate the development of good software. The course emphasizes the tools available in UNIX and Windows environments. Topics covered include compilers, debuggers, software design, and project management.]

**[CIS 404 Survey and Use of Software Libraries for Scientific Computing**
Spring. 1 credit. Usually weeks 5–8. Prerequisites: COM S 100 or equivalent programming experience; COM S 403/CIS 403 recommended but not required. S-U grades only.
Many software packages and code libraries have been developed for the solution of standard problems in scientific computing. Examples of such libraries are LAPACK, IMSL, Numerical Recipes routines, MATLAB functions, and routines available in online repositories such as Netlib. This course discusses how to link to or compile standard library formats and considers the legal and ethical aspects of using other people's code (or having them use yours). The course also surveys some of the standard problems and the available libraries and discusses the issues that arise in their use (e.g., accuracy, robustness, and generality).]

**[CIS 409 Data Structures and Algorithms for Computational Science**
Fall. 4 credits. Prerequisite: COM S 211 or equivalent programming experience. Not offered every year.
Covers data structures and algorithms with emphasis on those useful for computational

science. This course is intended for students outside of the Department of Computer Science whose work involves a significant amount of computing. Topics include basic data structures as well as more advanced topics. Emphasis is placed on the use of abstract data types and on how best to select appropriate data structures.]

**CIS 490 Independent Reading and Research**
Fall, spring. 1–4 credits.
Independent reading and research for undergraduates.

**[CIS 565 Computer Animation (also ART 372, COM S 565; formerly CIS/COM S 518)**
Fall. 4 credits. Prerequisite: COM S/ENGRD 211.
This course introduces students to various advanced animation techniques, including modeling, 2D key cel animation, motion and kinematics, lighting and materials, 3D key frame animation, physically based simulation, special effects, story boarding, and cinematography. The first half of the course consists of lectures/seminars and some didactic project assignments with supplemental reading assignments. The second half consists of a final project in which students may work in groups to create an original work of computer animation.]

**CIS 572 Heuristic Methods for Optimization (also CEE 509, COM S 572, OR&IE 533)**
Fall. 3 or 4 credits. Prerequisite: COM S/ENGRD 211 or 322, or CEE/ENGRD 241, or graduate standing, or permission of instructor.
For description, see CEE 509.

**CIS 576 Decision Theory I (also ECON 476, 676)**
Fall. 4 credits. Prerequisites: mathematical sophistication.

**CIS 577 Decision Theory II (also ECON 477, 677)**
Spring. 4 credits. Prerequisites: Mathematical sophistication.

**CIS 673 Integration of Artificial Intelligence and Operations Research (also COM S 673)**
Spring. 3 credits.
For description, see COM S 673.

**CIS 750 Evolutionary Computation and Design Automation (also COM S 750, M&AE 650)**
Fall. 4 credits. Prerequisite: programming experience or permission of instructor. Not offered every year.

**[CIS 751 Media Research and Critical Design (also COM S 751)**
Fall. 4 credits. Prerequisites: graduate standing in COM S or equivalent ability to read technical research papers. Contact instructor if unsure of qualifications. Not offered every year.]

**[CIS 752 Seminar on Scholarly Information Architecture**
Fall. 3 credits. Prerequisite: concurrent enrollment in COM S 431 or equivalent experience. S-U grades only. Not offered every year.]

**CIS 790 Independent Research**
Fall, spring. Variable credit. Prerequisite: permission of a CIS faculty member.
Independent research or master of engineering project.

## COMPUTER SCIENCE

The Department of Computer Science is affiliated with both the College of Arts and Sciences and the College of Engineering. Students in either college may major in computer science. The department is also part of CIS, and its courses are an integral part of its several educational programs.

**COM S 099 Fundamental Programming Concepts**
Fall, summer. 2 credits. No prerequisites. S-U grades only. Credit cannot be applied toward the Engineering degree. Freshmen only.
This course is designed for students who intend to take COM S 100 but are not adequately prepared for that course. Basic programming concepts and problem analysis are studied. An appropriate high-level programming language is used. Students with previous programming experience and students who do not intend to take COM S 100 should not take this course.

**COM S 100 Introduction to Computer Programming**
Fall, spring, summer. 4 credits.
An introduction to elementary computer programming concepts. Emphasis is on techniques of problem analysis and the development of algorithms and programs. There are two versions of the course. Both provide adequate preparation for COM S/ENGRD 211. Both versions are not offered every semester.

**COM S 100M Introduction to Computer Programming**
Corequisite: MATH 111, 191, or equivalent.
This version starts with a seven-week introduction to programming in MATLAB. Iteration, functions, and arrays are introduced. During the second seven weeks of the course students examine how these ideas are handled in the object-oriented framework provided by the Java programming language. Throughout the course, examples and assignments are chosen to give the student an appreciation for computational science and engineering. The pace of the course assumes that the student has no prior programming experience.

**COM S 100J Introduction to Computer Programming**
This course is an introduction to programming using the Java programming language. A two-week unit on MATLAB is included. Topics include algorithms, language concepts, selection, repetition, functions, objects and classes, arrays, strings, and inheritance. Principles of software development and style are emphasized. The course assumes basic high school mathematics (no calculus) but no programming experience.

**COM S 101 Introduction to Cognitive Science (also COGST 101, LING 170, PHIL 191, and PSYCH 102)**
Fall, summer. 3 credits.
For description, see COGST 101.

**COM S 113 Introduction to C**
Fall, spring. 1 credit. Usually weeks 1–4. Prerequisite: COM S 100 or equivalent programming experience. Credit is granted for both COM S 113 and 213 only if 113 is taken first. S-U grades only.
A brief introduction to the C programming language and standard libraries. Unix accounts are made available for students wishing to use that system for projects, but familiarity with Unix is not required. (Projects may be done using any modern implementation of C.) COM S 213 (C++ Programming) includes much of the material covered in 113. Students planning to take COM S 213 normally do not need to take 113.

**COM S 114 Unix Tools**
Fall. 1 credit. Usually weeks 5–8. Prerequisite: COM S 100 or equivalent programming experience. S-U grades only.
An introduction to Unix, emphasizing tools for file management, communication, process control, managing your Unix environment, and rudimentary shell scripts. Knowledge of at least one programming language is encouraged. Projects assume no previous knowledge of Unix or expertise in any particular language.

**COM S 130 Introductory Design and Programming for the Web (also INFO 130)**
Fall. 3 credits. No prerequisites.
The World Wide Web is both a technology and a pervasive and powerful resource in our society and culture. To build functional and effective web sites, students need technical and design skills as well as analytical skills for understanding who is using the web, in what ways they are using it, and for what purposes. In this course, students develop skills in all three of these areas through the use of technologies such as XHTML, Cascading Stylesheets, and PHP. Students study how web sites are deployed and used, usability issues on the web, user-centered design, and methods for visual layout and information architecture. Through the web, this course provides an introduction to the interdisciplinary field of information science. No computer background necessary.

**COM S 165 Computing in the Arts (also CIS 165, MUSIC 165)**
Fall. 3 credits.
For description, see CIS 165.

**COM S 167 Visual Imaging in the Electronic Age (also CIS 167, ENGRI 167)**
Spring. 3 credits. S-U grade optional.
For description, see CIS 167.

**[COM S 172 Computation, Information, and Intelligence (also COGST 172 and ENGRI 172)**
Fall. 3 credits. Prerequisites: some knowledge of differentiation required; permission of instructor required for students who have completed the equivalent of COM S 100. Not offered fall 2004.
An introduction to computer science using methods and examples from the field of artificial intelligence. Topics include game playing, search techniques, learning theory, compute-intensive methods, data mining, information retrieval, the web, natural language processing, and the Turing test. This is not a programming course; rather, "pencil and paper" problem sets will be assigned. Some calculus required.]

**COM S 201 Cognitive Science in Context Laboratory (also COGST 201 and PSYCH 201)**
Spring. 4 credits. Limited to 24 students. Prerequisite: concurrent or prior registration in Introduction to Cognitive Science (PSYCH 102/COGST 101/COM S 101/LING 170/PHIL 191) is suggested but not required. Knowledge of programming languages is not assumed. Fall, B. Halpern and staff; spring, D. Field and staff.
For description, see COGST 201.

**COM S 211 Computers and Programming (also ENGRD 211)**
Fall, spring, summer. 3 credits. Prerequisite: COM S 100 or an equivalent course in Java or C++.
Intermediate programming in a high-level language and introduction to computer science. Topics include program structure and organization, object-oriented programming (classes, objects, types, sub-typing), graphical user interfaces, algorithm analysis (asymptotic complexity, big "O" notation), recursion, data structures (lists, trees, stacks, queues, heaps, search trees, hash tables, graphs), simple graph algorithms. Java is the principal programming language.

**COM S 212 Java Practicum**
Fall, spring, summer. 1 credit. Letter grade only. Pre- or corequisite: COM S/ENGRD 211.
A project course that introduces students to the ways of software engineering using the Java programming language. The course requires the design and implementation of several large programs.

**[COM S 213 C++ Programming**
Spring. 2 credits. Prerequisite: COM S 100 or equivalent programming experience. Students who plan to take COM S 113 and 213 must take 113 first. S-U grades only.
An intermediate level introduction to the C++ programming language and the C/C++ standard libraries. Topics include basic statements, declarations, and types; stream I/O; user defined classes and types; derived classes, inheritance, and object-oriented programming; exceptions and templates. Recommended for students who plan to take advanced courses in computer science that require familiarity with C++ or C. Students planning to take COM S 213 normally do not need to take COM S 113; 213 includes most of the material taught in 113.]

**COM S 214 Advanced UNIX Programming and Tools**
Spring. 1 credit. S-U grades only. Usually weeks 5–8. Prerequisite: COM S 114 or equivalent.
A focus on Unix as a programming environment for people with a basic knowledge of Unix and experience programming in at least one language. Projects cover advanced shell scripts (sh, ksh, csh), Makefiles, programming and debugging tools for C and other languages, and more modern scripting languages such as Perl and Python. Students with little or no experience with Unix should take COM S 114 first.

**COM S 215 Introduction to C#**
Fall, spring. 1 credit. S-U grades only. Usually weeks 5–8. Prerequisite: COM S/ENGRD 211 or equivalent experience.
Introduces students to building applications in the .NET environment using the C# language.

**COM S 230 Intermediate Design and Programming for the Web (also INFO 230)**
Spring. 3 credits. Prerequisite: COM S 130 or equivalent knowledge.
Web programming requires the cooperation of two machines: the one in front of the viewer (client) and the one delivering the content (server). COM S 130 concentrates almost exclusively on the client side. The main emphasis in COM S 230 is learning about server side processing. Students begin by looking at interactions with databases, learning about querying both on paper and via SQL, and then, through a succession of projects, learn how to apply this understanding to the creation of an interactive data-driven site via the use of an integrated web site development tool such as ColdFusion. Also considered are techniques to enhance security, privacy, and reliability and ways of incorporating other programs. Toward the end of the course, students are shown how these development tools are working. Design issues are emphasized. A major component of the course is the creation of a substantial web site.

**COM S 280 Discrete Structures**
Fall, spring. 3 credits. Pre- or corequisite: COM S/ENGRD 211 or permission of instructor.
Covers mathematical aspects of programming and computing. Topics are chosen from the following: mathematical induction; logical proof; propositional and predicate calculus; combinatorics and discrete mathematics covering manipulation of sums, recurrence relations, and generating-function techniques; basic number theory; sets, functions, and relations; partially ordered sets; graphs; and algebraic structures.

**COM S 312 Data Structures and Functional Programming**
Fall, spring. 4 credits. Prerequisite: COM S 211/212 or equivalent programming experience. Should not be taken concurrently with COM S 314.
An advanced programming course that emphasizes functional programming techniques and data structures. Programming topics include recursive and higher-order procedures, models of programming language evaluation and compilation, type systems, and polymorphism. Data structures and algorithms covered include graph algorithms, balanced trees, memory heaps, and garbage collection. Also covered are techniques for analyzing program performance and correctness.

**COM S 314 Computer Organization (also ECE 314)**
Fall, spring. 4 credits. Prerequisite: COM S 211, COM S 312, or ENGRD 230 are recommended but not required. Should not be taken concurrently with COM S 312.
Basic computer organization. Topics include performance metrics, data formats, instruction sets, addressing modes, computer arithmetic, datapath design, memory hierarchies including caches and virtual memory, I/O devices, and bus-based I/O systems. Students learn assembly language programming and design a simple pipelined processor.

**[COM S 321 Numerical Methods in Computational Molecular Biology (also BIO BM 321 and ENGRD 321)**
Fall. 3 credits. Prerequisites: at least one course in calculus, such as MATH 106, 111, or 191 and a course in linear algebra, such as MATH 221 or 294 or BTRY 417. COM S 100 or equivalent and some familiarity with iteration, arrays, and procedures. Not offered fall 2004.
An introduction to numerical computing using MATLAB organized around five applications: the analysis of protein shapes, dynamics, protein folding, score functions, and field equations. Students become adept at plotting, linear equation solving, least squares fitting, and cubic spline interpolation. More advanced problem-solving techniques that involve eigenvalue analysis, the solution of ordinary and partial differential equations, linear programming, and nonlinear minimization will also be treated. The goal of the course is to develop a practical computational expertise with MATLAB and to build mathematical intuition for the problems of molecular biology. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, 421, or 428.]

**COM S 322 Introduction to Scientific Computation (also ENGRD 322)**
Spring, summer. 3 credits. Prerequisites: COM S 100 and MATH 221 or MATH 294.
An introduction to elementary numerical analysis and scientific computation. Topics include interpolation, quadrature, linear and nonlinear equation solving, least-squares fitting, and ordinary differential equations. The MATLAB computing environment is used. Vectorization, efficiency, reliability, and stability are stressed. Includes special lectures on parallel computation. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, 421, or 428.

**[COM S 324 Computational Linguistics (also COGST 424, LING 424)**
Fall, spring. 4 credits. Prerequisites: LING 203; labs involve work in the Unix environment; COM S 114 recommended.
For description, see LING 424.]

**COM S 330 Applied Database Systems (also INFO 330)**
Fall. 3 credits. Prerequisite: COM S 211/ENGRD 211. COM S majors may use only one of the following toward their degree: COM S/INFO 330 or COM S 433.
The course introduces students to modern database systems and three-tier application development with a focus on building web-based applications using database systems. Concepts covered include the relational model, relational query languages, data modeling, normalization, database tuning, three-tier architectures, Internet data formats and query languages, server- and client-side technologies, and an introduction to web services. Students build a database–backed web site.

**COM S 381 Introduction to Theory of Computing**
Fall, summer. 3 credits. Prerequisite: COM S 280 or permission of instructor. Credit will not be granted for both COM S 381 and COM S 481. Corrective transfers between COM S 381 and COM S 481 (in either direction) are encouraged during the first few weeks of instruction.

An introduction to the modern theory of computing: automata theory, formal languages, and effective computability.

**COM S 400 The Science of Programming**
Fall. 3 credits. Prerequisite: COM S 211. Covers the practical development of correct programs based on the conscious application of principles that are derived from a mathematical notion of program correctness. In addition, related ideas in algorithmic problem solving are explored.

**COM S 411 Programming Languages**
Fall. 4 credits. Prerequisite: COM S 312 or permission of instructor.
An introduction to the theory, design, and implementation of programming languages. Topics include operational semantics, type systems, higher-order function, scope, lambda calculus, laziness, exceptions, side effects, continuations, objects, and modules. Also discussed are logic programming, concurrency, and distributed and persistent programming.

**COM S 412 Introduction to Compilers**
Spring. 3 credits. Prerequisites: COM S 312 (or permission of instructor) and COM S 314. Corequisite: COM S 413.
An introduction to the specification and implementation of modern compilers. Topics covered include lexical scanning, parsing, type checking, code generation and translation, an introduction to optimization, and the implementation of modern programming languages. The course entails a substantial compiler implementation project.

**COM S 413 Practicum in Compilers**
Spring. 2 credits. Corequisite: COM S 412.
A compiler implementation project related to COM S 412.

**COM S 414 Systems Programming and Operating Systems**
Fall, spring, summer. 3 credits. Prerequisite: COM S 211, 212, 312 (or permission of instructor), and 314. Corequisite: COM S 415 in spring only.
An introduction to the logical design of systems programs, with emphasis on multiprogrammed operating systems. Topics include process synchronization, deadlock, memory management, input-output methods, information sharing, protection and security, and file systems. The impact of network and distributed computing environments on operating systems is also discussed.

**COM S 415 Practicum in Operating Systems**
Fall, spring. 2 credits. Corequisite: COM S 414.
The practical aspects of operating systems are studied through the design and implementation of an operating system kernel that supports multiprogramming, virtual memory, and various input-output devices. All the programming for the project is in a high-level language.

**COM S 419 Computer Networks (formerly COM S 519)**
Spring. 4 credits. Prerequisite: COM S 211, COM S 312, or ENGRD 230 are recommended but not required, or permission of instructor. Not offered every year.
An introduction to computer networks with an emphasis on evolving Internet standards. A detailed introduction is given to networking protocols for reliable data transfer, flow control, congestion control, naming and addressing, routing, security, management, and applications. Fundamentals of layered protocols and techniques for protocol design and implementation are covered. The course is project oriented and requires substantial programming experience in Java or C.

**COM S 421 Numerical Analysis**
Fall. 4 credits. Prerequisites: MATH 294 or equivalent, one additional mathematics course numbered 300 or above, and knowledge of programming.
Modern algorithms for systems of linear equations, systems of nonlinear equations, numerical optimization, and numerical solution of differential equations. Some discussion of methods suitable for parallel computation. This course requires more mathematical sophistication than COM S 322. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, 421, or 428.

**COM S 426 Introduction to Computational Biology**
Fall. 3 credits. Prerequisites: COM S/ ENGRD 211, COM S 280.
Computational biology is a relatively new field that is rooted in two different disciplines: computer science and molecular biology. It is concerned with the study of biological systems and phenomena, in search for explanations, rules, patterns, and regularities. The focus of this course is the set of algorithms, tools, and models used today to analyze biological data and recover and discover hidden information. These tools can be used to predict the function of new genes, discover hidden motifs that are biologically significant, study evolutionary processes, better understand cellular "computations," and aid in the development of new therapeutic agents for treatment of various diseases. Some of the topics covered are sequence analysis (alignment, multiple sequence alignment), motif detection, phylogenetic trees, secondary structure prediction, Hidden Markov Models, and analysis of gene expression data.

This course is intended mostly for students in the computational sciences because it focuses on algorithms and mathematical models. No knowledge of biology is needed (the course starts with a brief overview of the basic entities and the central dogma of molecular biology, and other relevant terms are introduced as needed).

**COM S 427 Practicum in Computational Biology**
Fall. 2 credits. Pre- or corequisite: COM S 426.
In this course, students develop a system or an application to analyze biological data. Possible applications are a database system to manipulate multiple data types, a learning system to detect hidden patterns in massive biological data sets, a software suite for sequence comparison or analysis of gene expression data, etc.

**COM S 428 Introduction to Computational Biophysics**
Fall. 3 credits. Prerequisite: COM S 100, CHEM 211 or equivalent, MATH 293 or 294, PHY 112 or 213, or permission of instructor; BIOBM 330 recommended.
This course teaches the techniques that are used to simulate on the computer the structure, dynamics, and function of biological molecules. Computer models of water/proteins/membranes using mechanical force fields are considered. Optimization methods (conjugate gradient and Newton Raphson minimization) are explained in the context of structure optimization. Stochastic sampling (Metropolis algorithm) is used to estimate entropy and partition functions. Enhanced sampling approaches such as multi-tempering to estimate free energies are discussed. Continuum approximation to dielectric and the numerical solution of the Poisson Boltzmann equation are explored. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, 421, or 428.

**COM S 430 Information Retrieval (also INFO 430)**
Fall. 3 credits. Prerequisite: COM S 211 or equivalent.
This course studies the methods used to search for and discover information in large-scale systems. The emphasis is on information retrieval applied to textual materials, but there is some discussion of other formats. The course includes techniques for searching, browsing, and filtering information and the use of classification systems and thesauruses. The techniques are illustrated with examples from web searching and digital libraries.

**COM S 431 Web Information Systems (also INFO 431)**
Spring. 3 credits. Prerequisites: COM S 211 and some familiarity with the technology of web sites.
This course examines the architecture of web information systems such as distributed digital libraries and electronic publishing systems. Many of the topics presented in the course are the subject of current research and development at Cornell, other universities, and in standards organizations such as the World Wide Web Consortium. Course content mixes exploration of current tools for building web information systems such XML, XSLT, and RDF with broader concepts such as techni-ques for knowledge representation and description, object models for content representation, and legal and economic impacts of web information. A theme that runs throughout the course is the relationship between traditional information environments, exemplified by libraries, and the distributed information environment of the web.

**COM S 432 Introduction to Database Systems**
Fall. 3 credits. Prerequisites: COM S 312, or 211/212, and permission of instructor. Recommended: COM S 213 and strong programming skills in C or C++.
An introduction to modern relational database systems. Concepts covered include storage structures, access methods, query languages, query processing and optimization, transaction processing, and database design theory. The course primarily covers the internals of database systems and includes four large programming assignments in C++.

**COM S 433 Practicum in Database Systems**
Fall. 2 credits. Corequisite: COM S 432. COM S majors may use only one of the following toward their degree: COM S/ INFO 330 or COM S 433.
An introduction to building web-database applications. Students implement a small e-commerce system using Active Server Pages, Java Server Pages, Cookies, and Servlets. The practicum also introduces technologies such

as XML/XPath/XSLT and WAP. COM S majors may use only one of the following toward their degree: COM S/INFO 330 or COM S 433.

**COM S 465 Computer Graphics I (also ARCH 374)**
Fall. 4 credits. Prerequisite: COM S/ENGRD 211. May not be taken after completion of COM S 417.
An introduction to the principles of computer graphics in two and three dimensions. Topics include digital images, filtering and anti-aliasing, 2D and 3D affine geometry, ray tracing, perspective and 3D viewing, the graphics pipeline, curves and surfaces, and human visual perception. Homework assignments require programming.

**COM S 467 Computer Graphics II**
Spring. 3 credits. Prerequisite: COM S 465.
This course covers the principles of computer graphics including advanced topics such as the modern graphics hardware pipeline, transformations, materials and shading models, advanced texturing, shadow algorithms, hierarchical acceleration structures, global illumination, animation, and 3D surface modeling.

**COM S 468 Computer Graphics Practicum**
Spring. 2 credits. Prerequisite: COM S 465. Corequisite: COM S 467.
This course provides COM S 467 students with hands-on experience in computer graphics programming on modern graphics hardware with a final 3D game project. Programming assignments cover 3D transformations, modeling, shading, rendering, animation, and user interfaces. The course uses Java, OpenGL, and Cg for code development.

**COM S 472 Foundations of Artificial Intelligence**
Fall. 3 credits. Prerequisites: COM S/ENGRD 211 and COM S 280 (or equivalent).
A challenging introduction to the major subareas and current research directions in artificial intelligence. Topics include knowledge representation, heuristic search, problem solving, natural-language processing, game-playing, logic and deduction, planning, and machine learning.

**COM S 473 Practicum in Artificial Intelligence**
Fall. 2 credits. Corequisite: COM S 472.
Project portion of COM S 472. Topics include knowledge representation systems, search procedures, game-playing, automated reasoning, concept learning, reinforcement learning, neural nets, genetic algorithms, planning, and truth maintenance.

**COM S 474 Introduction to Natural Language Processing (also COGST 474, LING 474)**
Fall. 4 credits. Prerequisites: COM S 211.
A computationally oriented introduction to natural language processing, the goal of which is to enable computers to use human languages as input, output, or both. Possible topics include parsing, grammar induction, information retrieval, and machine translation.

**COM S 478 Machine Learning**
Spring. 4 credits. Prerequisites: COM S 280, 312, and basic knowledge of linear algebra and probability theory.
Learning and classifying are two of our basic abilities. Machine learning is concerned with the question of how to train computers to learn from experience, to adapt and make decisions accordingly. This course introduces the set of techniques and algorithms that constitute machine learning as of today, including inductive inference of decision trees, the parametric-based Bayesian learning approach, Bayesian belief networks and Hidden Markov Models, non-parametric methods, discriminent functions and support vector machines, neural networks, stochastic methods such as genetic algorithms, unsupervised learning and clustering, and other issues in the theory of machine learning. These techniques are used today to automate procedures that were previously performed by humans as well as to explore untouched domains of science.

**COM S 480 Introduction to Cryptology (also MATH 335)**
Fall, spring. 3 credits. Prerequisites: COM S 100 and MATH 222 or 294. Students who take this course may not also receive credit for MATH 336.
For description, see MATH 335.

**COM S 481 Introduction to Theory of Computing**
Fall. 4 credits. Prerequisite: COM S 280 or permission of instructor. Credit will not be granted for both COM S 381 and 481. Corrective transfers between COM S 481 and 381 (in either direction) are encouraged during the first few weeks of instruction.
A faster-moving and deeper version of COM S 381.

**COM S 482 Introduction to Analysis of Algorithms**
Spring, summer. 4 credits. Prerequisites: COM S 280, 312, and either 381 or 481, or permission of instructor.
Techniques used in the creation and analysis of algorithms. Combinatorial algorithms, computational complexity, NP-completeness, and intractable problems.

**COM S 483 Quantum Computation (also PHYS 481 and 681)**
Spring. 2 credits. Prerequisite: familiarity with the theory of vector spaces over the complex numbers. Not offered every year.
For description, see PHYS 481.

**COM S 486 Applied Logic (also MATH 486)**
Fall or spring. 4 credits. Prerequisites: MATH 222 or 294, COM S 280 or equivalent (such as MATH 332, 432, 434, 481), and some additional course in mathematics or theoretical computer science.
Propositional and predicate logic, compactness and completeness by tableaux, natural deduction, and resolution. Equational logic. Herbrand Universes and unification. Rewrite rules and equational logic, Knuth-Bendix method, and the congruence-closure algorithm and lambda-calculus reduction strategies. Topics in Prolog, LISP, ML, or Nuprl. Applications to expert systems and program verification.

**COM S 490 Independent Reading and Research**
Fall, spring. 1–4 credits.
Independent reading and research for undergraduates.

**COM S 501 Software Engineering**
Spring. 4 credits. Prerequisite: COM S 211 or equivalent experience programming in Java or C++.
An introduction to the practical problems of specifying, designing, and building large, reliable software systems. Students work in teams on projects for real clients. This work includes a feasibility study, requirements analysis, object-oriented design, implementation, testing, and delivery to the client. Additional topics covered in lectures include professionalism, project management, and the legal framework for software development.

**COM S 504 Applied Systems Engineering (also CEE 504, ECE 512, M&AE 591, OR&IE 512, SYSEN 510)**
Fall. 3 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor.
For description, see SYSEN 510.

**COM S 505 Systems Architecture, Behavior, and Optimization (also CEE 505, ECE 513, M&AE 592, OR&IE 513, SYSEN 520)**
Spring. 3 credits. Prerequisite: Applied System Engineering (CEE 504, COM S 504, ECE 512, M&AE 591, OR&IE 512, SYSEN 510).
For description, see SYSEN 520.

**COM S 513 System Security**
Fall. 4 credits. Prerequisites: COM S 414 or 419 and familiarity with JAVA or C# programming languages.
This course discusses security and survivability for computers and communications networks. The course includes discussions of policy issues (e.g., the national debates on cryptography policy) as well as the discussions of the technical alternatives for implementing the properties that comprise "trustworthiness" in a computing system. Mechanisms for authorization and authentication as well as cryptographic protocols are covered.

**COM S 514 Intermediate Computer Systems**
Spring. 4 credits. Prerequisites: COM S 414 or permission of instructor.
This course focuses on practical issues in designing and implementing distributed software. Topics vary depending upon instructor. Recent offerings have covered object-oriented software development methodologies and tools, distributed computing, fault-tolerant systems, and network operating systems or databases. Students undertake a substantial software project. Many students obtain additional project credit by coregistering in COM S 490, 515, or 790.

**COM S 522 Computational Tools and Methods for Finance**
Spring. 4 credits. Prerequisites: programming experience (e.g., C, FORTRAN, or MATLAB), some knowledge of numerical methods, especially numerical linear algebra. Not offered every year.
This course provides a hands-on introduction to computational methods and tools used in finance. Students study both the underlying methods and efficient implementation. The MATLAB Financial Toolbox, along with additional MATLAB tools, are used

extensively. The underlying numerical techniques discussed include nonlinear least-squares procedures (regression), basic linear algebra, linear and nonlinear optimization, finite-difference methods for PDEs, quadratic programming (and linear complementarity problems), and specialized tree (and lattice) evaluation methods.

**COM S 530 The Architecture of Large-Scale Information Systems (also INFO 530)**
Spring. 4 credits. Prerequisite: COM S/INFO 330 or COM S 432.
This course deals with the architecture of large-scale information systems, with special emphasis on Internet-based systems. Topics covered include three-tier architectures, edge caches, distributed transaction management, web services, workflows, performance scalability, and high-availability architectures. The course includes a substantial project in the context of three-tier architectures, involving web servers, application servers, and database systems. Students study and use technologies such as Web Services, .Net, J2EE, ASPs, Servlets, XML, and SOAP.

**COM S 565 Computer Animation (also ART 372, CIS 565; formerly CIS/COM S 518)**
Fall. 4 credits. Prerequisite: COM S/ENGRD 211.
For description, see ART 372.

**COM S 572 Heuristic Methods for Optimization (also CEE 509, CIS 572, OR&IE 533**
Fall. 3 or 4 credits. Prerequisites: COM S/ENGRD 211 or 322 or CEE/ENGRD 241, or graduate standing, or permission of instructor. Not offered every year.
For description, see CEE 509.

**COM S 578 Empirical Methods in Machine Learning and Data Mining**
Fall. 4 credits. Prerequisites: COM S 280 and 312 or equivalent.
This implementation-oriented course presents a broad introduction to current algorithms and approaches in machine learning, knowledge discovery, and data mining and their application to real-world learning and decision-making tasks. The course also covers experimental methods for comparing learning algorithms, for understanding and explaining their differences, and for exploring the conditions under which each is most appropriate.

**COM S 611 Advanced Programming Languages**
Fall. 4 credits. Graduate standing or permission of instructor.
A study of programming paradigms: functional, imperative, concurrent, and logic programming. Models of programming languages, including the lambda calculus. Type systems, polymorphism, modules, and other object-oriented constructs. Program transformations, programming logic, and applications to programming methodology.

**COM S 612 Compiler Design for High-Performance Architectures**
Spring. 4 credits. Prerequisites: COM S 314 and 412 or permission of instructor.
Compiler design for pipelined and parallel architectures. Program analysis: data and control dependencies, dataflow analysis, efficient solution of dataflow equations, dependence tests, solution of Diophantine equations. Architecture and code generation for instruction-level parallel (ILP) processors: pipelined, VLIW and superscalar architectures, code reorganization and software pipelining. Architecture and code generation for multi-processors: shared- and distributed-memory architectures, latency tolerance and avoidance, loop transformations to enhance parallelism and locality of reference.

**COM S 614 Advanced Systems**
Spring. 4 credits. Prerequisite: COM S 414 or permission of instructor.
An advanced course in systems, emphasizing contemporary research in distributed systems. Topics may include communication protocols, consistency in distributed systems, fault-tolerance, knowledge and knowledge-based protocols, performance, scheduling, concurrency control, and authentication and security issues.

**COM S 615 Peer-to-Peer Systems**
Spring. 4 credits. Prerequisites: COM S 614 recommended.
Peer-to-peer (P2P) is a new paradigm for distributed computing. P2P systems lack centralized servers and rely on self-organization and peer-to-peer resource sharing to accomplish their tasks. In this course, we examine the peer-to-peer paradigm, examine peer-to-peer systems, and discuss existing and new applications. Students are expected to perform an in-depth study of an existing approach or to develop new peer-to-peer systems and applications as part of the course project.

**COM S 619 Advanced Computer Networks**
Fall. 4 credits. Prerequisite: COM S 419 or COM S 519, or permission of instructor. Not offered every year.
This course examines advanced computer network topics such as overlay and P2P networking, reliable multicast, mobility, voice over IP, header compression, security, and extreme networking environments (fast, slow, big, long). The emphasis is on both research and the latest standards. A project with research content is required.

**COM S 621 Matrix Computations**
Fall. 4 credits. Prerequisites: MATH 411 and 431 or permission of instructor.
Stable and efficient algorithms for linear equations, least squares, and eigenvalue problems. Direct and iterative methods are considered. The MATLAB system is used extensively.

**COM S 622 Numerical Optimization and Nonlinear Algebraic Equations**
Spring. 4 credits. Prerequisite: COM S 621. Offered odd-numbered years only.
Modern algorithms for the numerical solution of multidimensional optimization problems and simultaneous nonlinear algebraic equations. Emphasis is on efficient, stable, and reliable numerical techniques with strong global convergence properties: quasi-Newton methods, modified Newton algorithms, and trust-region procedures. Special topics may include large-scale optimization, quadratic programming, and numerical approximation.

**[COM S 624 Numerical Solution of Differential Equations**
Spring. 4 credits. Prerequisites: previous exposure to numerical analysis (e.g., COM S 421 or 621) and differential equations, and knowledge of MATLAB. Offered in even-numbered years.
Finite difference methods for the solution of ordinary and partial differential equations. A fast-moving course that begins with a three-week survey of numerical methods for ODEs, then moves on to Fourier analysis and methods for PDEs, especially parabolic and hyperbolic equations. Other topics covered include numerical stability, finite element methods, Hamiltonian problems, and computational issues such as mesh generation and sparse matrix computation for PDES.]

**COM S 626 Computational Molecular Biology**
Spring. 3 credits. Prerequisites: familiarity with linear programming, numerical solutions of ordinary differential equations, and nonlinear optimization methods.
Problems and algorithms in computational molecular biology. Topics include sequences (alignment, scoring functions, complexity of searches and alignment, secondary structure prediction, families, and function), the protein folding problem (lattice models, lattice searches, the HP model, chemical potentials, statistical potentials, funnels, complexity and model verification, global optimization, homology, threading), and the dynamics of complex biosystems (the Molecular Dynamics method, long-range forces, statistics of flexible systems, reduced models).

**COM S 627 Computational Biology: The Machine Learning Approach**
Spring. 3 credits. Prerequisites: COM S 426 or 626 and COM S 478 or 578 or permission of instructor.
This is a graduate-level course in computational biology that focuses on machine learning models and their application to computational problems in biology. Some topics covered are supervised (Support Vector Machines, Hidden Markov Models, deterministic and probabilistic suffix trees) and unsupervised (embedding, PCA, ICA, clustering) learning in computational biology, advanced statistical analysis of sequences, analysis of microarrays, and modeling of complex systems (Bayesian Belief Networks, DEA).

**COM S 630 Representing and Accessing Digital Information (also INFO 630)**
Fall. 4 credits. Prerequisites: COM S 472 or 478 or 578 or the equivalent.
This course covers the representation, organization, and access of digital information with an emphasis on textual information. Topics include structured and semistructured data, information retrieval, natural language processing, and machine learning, with links to work in databases, data mining, and computational linguistics.

**COM S 632 Database Systems**
Spring. 4 credits. Prerequisite: COM S 432/433 or permission of instructor.
A variety of advanced issues ranging from transaction management to query processing to data mining. Involves extensive paper reading and discussion. Development of a term project with research content is required.

**COM S 633 Advanced Database Systems**
Spring. 4 credits.
This course covers advanced topics in database systems and data mining. The exact set of topics covered changes with each offering of the course.

**COM S 664 Machine Vision**
Fall. 4 credits. Prerequisites: undergraduate level understanding of algorithms and MATH 221 or equivalent.
An introduction to computer vision, with an emphasis on discrete optimization algorithms and on applications in medical imaging. The following topics are covered: edge detection, image segmentation, stereopsis, motion and optical flow, active contours, and the Hausdorff distance. Students are required to implement several of the algorithms covered in the course and complete a final project.

**COM S 665 Advanced Rendering**
Fall or spring. 4 credits. Prerequisites: COM S 465 and 467 or equivalent and an undergraduate-level understanding of algorithms, probability and statistics, vector calculus, and programming.
This course covers advanced topics in realistic rendering with a focus on interactive techniques. Topics include light transport and global illumination, Monte-Carlo rendering, rendering using the modern graphics pipeline, interactive global illumination, shadow algorithms, perception for rendering, and image-based rendering.

**COM S 667 Physically Based Rendering**
Fall or spring. 4 credits. Prerequisites: COM S 465 and 467 or equivalent and an undergraduate-level understanding of algorithms, programming, and vector calculus. Offered spring 2004.
An advanced course in realistic image synthesis, focusing on the computation of physically accurate images. Topics include radiometry; light transport and global illumination; rendering with participating media; advanced models for material properties; and physical measurement of light sources, images, and materials.

**COM S 671 Introduction to Automated Reasoning**
Fall or spring. 4 credits. Prerequisite: (COM S 611 and graduate standing) or permission of instructor.
Topics in modern logic needed to understand and use automated reasoning systems such as HOL, Nuprl, and PVS. Special emphasis is on type theory and logic and on tactic-oriented theorem proving.

**COM S 672 Advanced Artificial Intelligence**
Spring. 4 credits. Prerequisites: COM S 472 or permission of instructor.
Artificial intelligence (AI) provides many computational challenges. This course covers a variety of areas in AI, including knowledge representation, automated reasoning, learning, game-playing, and planning, with an emphasis on computational issues. Specific topics include stochastic reasoning and search procedures, properties of problem encodings, issues of syntax and semantics in knowledge representation, constraint satisfaction methods and search procedures, and critically constrained problems and their relation to phase-transition phenomena. In addition, connections between artificial intelligence and other fields, such as statistical physics, operations research, and cognitive science are explored.

**COM S 673 Integration of Artificial Intelligence and Operations Research (also CIS 673)**
Spring. 3 credits.
This course covers topics on the integration of artificial intelligence (AI) and operations research (OR) techniques for solving combinatorial problems as they appear in AI and OR applications. Application domains include AI planning, scheduling, combinatorial auctions, market mechanisms, and combinatorial designs.

**COM S 674 Natural Language Processing**
Spring. 3 credits. Prerequisites: COM S 472 or permission of instructor. COM S 474 is NOT a prerequisite. Not offered every year.
This course presents a graduate-level introduction to natural language processing, the primary concern of which is the study of human language use from a computational perspective. The course covers syntactic analysis, semantic interpretation, and discourse processing, examining both symbolic and statistical approaches. Possible topics include information extraction, natural language generation, memory models, ambiguity resolution, finite-state methods, mildly context-sensitive formalisms, deductive approaches to interpretation, machine translation, and machine learning of natural language.

**[COM S 676 Reasoning about Knowledge**
Fall. 4 credits. Prerequisites: mathematical maturity and an acquaintance with propositional logic.
Knowledge plays a crucial role in distributed systems, game theory, and artificial intelligence. Material examines formalizing reasoning about knowledge and the extent to which knowledge is applicable to those areas. Issues include common knowledge, knowledge-based programs, applying knowledge to analyzing distributed systems, attainable states of knowledge, modeling resource-bounded reasoning, and connections to game theory.]

**[COM S 677 Reasoning about Uncertainty**
Fall. 4 credits. Prerequisites: mathematical maturity and an acquaintance with propositional logic.
Examines formalizing reasoning about and representing uncertainty, using formal logical approaches as a basis. Topics: logics of probability, combining knowledge and probability, probability and adversaries, conditional logics of normality, Bayesian networks, qualitative approaches to uncertainty, going from statistical information to degrees of belief, and decision theory.]

**COM S 678 Advanced Topics in Machine Learning**
Spring. 4 credits. Prerequisites: COM S 478 or equivalent, or COM S 578 or equivalent, or permission of instructor.
This course extends and complements COM S 478 and COM S 578, giving in-depth coverage of new and advanced methods in machine learning. In particular, we connect to open research questions in machine learning, giving starting points for future work. The content of the course reflects an equal balance between learning theory and practical machine learning, making an emphasis on approaches with practical relevance. Topics include support vector machines, clustering, Bayes nets, boosting, model selection, learning orderings, and inductive transfer.

**COM S 681 Analysis of Algorithms**
Fall. 4 credits. Prerequisite: COM S 482 or graduate standing.
Methodology for developing efficient algorithms, primarily for graph theoretic problems. Understanding of the inherent complexity of natural problems via polynomial-time algorithms, randomized algorithms, NP-completeness, and randomized reducibilities. Also covers topics such as parallel algorithms and efficient data structures.

**COM S 682 Theory of Computing**
Spring. 4 credits. Prerequisite: (COM S 381 or 481) and (COM S 482 or 681) or permission of instructor.
Advanced treatment of theory of computation, computational-complexity theory, and other topics in computing theory.

**[COM S 683 Advanced Design and Analysis of Algorithms**
Spring. 4 credits. Prerequisites: COM S 681 or permission of instructor. Not offered every year.]

**[COM S 684 Algorithmic Game Theory**
Spring. 4 credits. Prerequisite: background in algorithms and graphs at the level of COM S 482. No prior knowledge of game theory or economics is assumed.
Algorithmic game theory combines algorithmic thinking with game-theoretic or, more generally, economic concepts. The course focuses on problems arising from, and motivated by, the Internet and other decentralized computer networks. The most defining characteristic of the Internet is that it was not designed by a single central entity, but emerged from the complex interaction of many economic agents, such as network operators, service providers, designers, users, etc., in varying degrees of collaboration and competition. The course focuses on some of the many questions at the interface between algorithms and game theory that arise from this point of view. Topics include Nash equilibrium and general equilibrium, the price of anarchy, market equilibrium, social choice theory, mechanism design, multicast pricing, and more.]

**COM S 685 The Structure of Information Networks (also INFO 685)**
Spring. 4 credits. Prerequisite: COM S 482.
Information networks such as the World Wide Web are characterized by the interplay between heterogeneous content and a complex underlying link structure. This course covers recent research on algorithms for analyzing such networks and models that abstract their basic properties. Topics include combinatorial and probabilistic techniques for link analysis, centralized and decentralized search algorithms, generative models for networks, and connections with work in the areas of social networks and citation analysis.

**[COM S 686 Logics of Programs**
Spring. 4 credits. Prerequisites: COM S 481, 682, and MATH 481 or MATH/COM S 486. Not offered every year.]

**COM S 709 Computer Science Colloquium**
Fall, spring. 1 credit. S-U grades only. For staff, visitors, and graduate students interested in computer science.
A weekly meeting for the discussion and study of important topics in the field.

**COM S 711 Seminar in Advanced Programming Languages**
Fall, spring. 3 credits.

**COM S 713 Seminar in Systems and Methodology**
Fall, spring. 4 credits. Prerequisites: a graduate course employing formal reasoning such as COM S 611, 613, 671, a logic course, or permission of instructor. Not offered every year.
Discussion of contemporary issues in the design and analysis of computing systems. Emphasis is on the proper use of rigor, models, and formalism.

**COM S 715 Seminar in Programming Refinement Logics**
Fall, spring. 4 credits. Prerequisite: permission of instructor.
Topics in programming logics, possibly including type theory, constructive logic, decision procedures, heuristic methods, extraction of code from proofs, and the design of proof-development and problem-solving systems.

**COM S 717 Topics in Parallel Architectures**
Fall. 4 credits. Prerequisite: COM S 612 or permission of instructor. Not offered every year.
Covers topics in parallel computers. Material includes: architectures of parallel computers, parallelizing compilers, operating systems for parallel computers, and languages (functional and logic-programming languages) designed for parallel computation.

**COM S 718 Computer Graphics Seminar**
Fall, spring. 4 credits.

**COM S 719 Seminar in Programming Languages**
Fall, spring. 4 credits. Prerequisite: COM S 611 or permission of instructor. S-U grades only.

**COM S 721 Topics in Numerical Analysis**
Fall, spring. 4 credits. Prerequisite: COM S 621 or 622 or permission of instructor. Not offered every year; semester TBA.
Topics are chosen at instructor's discretion.

**COM S 726 Problems and Perspectives in Computational Molecular Biology (also PL BR 726)**
Fall, spring. 1 credit. S-U grades only.
This is a weekly seminar series discussing timely topics in computational molecular biology. The course addresses methodological approaches to sequence and structure analysis, function prediction, study of evolutionary relationships, and analysis of large biological systems. Statistical and deterministic computational approaches are covered, and specific and detailed biological examples are discussed. In each topic, we select one or two representative papers that made significant advances in this field. The lectures are given by faculty and students. The seminar is open to all from the life sciences, computational sciences, and physical sciences. We try to bridge these disciplines by pairing students/faculty from complementary backgrounds.

**COM S 732 Seminar in Database Systems**
Fall, spring. 4 credits. S-U grades only.

**COM S 750 Evolutionary Computation and Design Automation (also CIS 750, M&AE 650)**
Fall. 4 credits. Prerequisite: programming experience or permission of instructor.
Seminar course in evolutionary algorithms and their application to optimization and open-ended computational design. Genetic algorithms, genetic programming, co-evolution, arms races and cooperation, developmental representations, learning, and symbiosis are covered. Topics include artificial life, evolutionary robotics, and applications in a variety of domains in science and engineering. Suitable for students interested in computational techniques for addressing open-ended design problems and in computational models of evolutionary discovery.

**[COM S 751 Media Research and Critical Design (also CIS 751)**
Fall. 4 credits. Prerequisites: graduate standing in COM S or equivalent ability to read technical research papers. Contact instructor if unsure of qualifications. Not offered every year.]

**[COM S 752 Seminar on Scholarly Information Architecture (also CIS 752)**
Fall. 3 credits. Prerequisite: concurrent enrollment in COM S 502 or equivalent experience. S-U grades only. Not offered every year.]

**COM S 754 Systems Research Seminar**
Fall, spring. 1 credit. S-U grades only.

**COM S 772 Seminar in Artificial Intelligence**
Fall, spring. 4 credits. Prerequisites: permission of instructor. S-U grades only.

**COM S 775 Seminar in Natural Language Understanding**
Fall, spring. 2 credits.
Informal weekly seminar in which current topics in natural language understanding and computational linguistics are discussed.

**COM S 786 Introduction to Kleene Algebra**
Spring. 4 credits. Prerequisites: COM S 481 required; COM S 482 or 681, COM S 682, elementary logic (MATH 481 or 681), algebra (MATH 432) recommended.
Kleene algebra is an algebraic system that axiomatically captures the properties of a natural class of structures arising in logic and computer science. It has appeared in various guises in relational algebra, semantics and logics of programs, automata and formal language theory, and the design and analysis of algorithms. In this course, we review the history of the development of Kleene algebra and Kleene algebra with tests (Kleene/Boolean algebra). We study models, compare axiomatizations, and derive completeness, expressiveness, and complexity results. We also discuss various applications in program schematology, program verification, compiler optimization, and programming language semantics and logic.

**COM S 789 Seminar in Theory of Algorithms and Computing**
Fall, spring. 4 credits. Prerequisite: permission of instructor. S-U grades only.

**COM S 790 Special Investigations in Computer Science**
Fall, spring. Prerequisite: permission of a computer science adviser. Letter grade only.
Independent research or Master of Engineering project.

**COM S 990 Special Investigations in Computer Science**
Fall, spring. Prerequisite: permission of a computer science adviser. S-U grades only.
Doctoral research.

## INFORMATION SCIENCE (INFO)

**INFO 130 Introductory Design and Programming for the Web (also COM S 130)**
Fall. 3 credits.
For description, see COM S 130.

**INFO 214 Cognitive Psychology (also COGST 214, PSYCH 214)**
Fall. 3 credits. Sophomore standing required. Limited to 175 students. Graduate students: see INFO 614, PSYCH 614, or COGST 501.
For description, see PSYCH 214.

**INFO 230 Intermediate Design and Programming for the Web (also COM S 230)**
Spring. 3 credits. Prerequisite: COM S/INFO 130 or equivalent knowledge.
For description, see COM S 230.

**INFO 245 Psychology and Social Computing (also COMM 245)**
Fall. 3 credits.
For description, see COMM 245.

**INFO 292 Inventing an Information Society (also ECE 298, ENGRG 298, HIST 292, S&TS 292)**
Spring. 3 credits.
For description, see ENGRG 298.

**INFO 295 Information Modeling**
Fall. 4 credits. Corequisite: MATH 231 or equivalent.
This course teaches basic mathematical concepts in information modeling. Topics covered include graph theory, discrete probability, finite automata, Markov models, and hidden Markov models. We use examples and applications from various areas of information science such as the structure of the web, genome sequences, natural languages, and signal processing.

**INFO 330 Applied Database Systems (also COM S 330)**
Fall. 3 credits. Prerequisites: COM S 211/ENGRD 211.
For description, see COM S 330.

**INFO 345 Human-Computer Interaction Design (also COMM 345)**
Spring. 3 credits.
For description, see COMM 345.

**[INFO 349 Media Technologies (also S&TS 349)**
Spring. 3 credits. Not offered spring 2005.
For description, see S&TS 349.]

**INFO 355 Computers: From Babbage to Gates (also S&TS 355)**
Spring. 4 credits.
For description, see S&TS 355.

**[INFO 387 The Automatic Lifestyle: Consumer Culture and Technology (also S&TS 387)**
Spring. 4 credits. Not offered spring 2005.
For description, see S&TS 387.]

**INFO 430 Information Discovery (also COM S 430)**
Fall. 3 credits. Prerequisite: COM S 211/ ENGRD 211 or equivalent.
For description, see COM S 430.

**INFO 431 Web Information Systems (also COM S 431)**
Spring. 3 credits. Prerequisites: COM S 211 and some familiarity with the technology of web sites.
For description, see COM S 431.

**INFO 435 Seminar on Applications of Information Science (also INFO 635)**
Spring. 3 credits. Prerequisites: background in computing, data structures, and programming at the level of COM S 211 or equivalent, and experience in using information systems. Undergraduates and masters students should register for INFO 435. Ph.D. students should register for INFO 635.
This seminar course examines the technological, sociological, legal, financial, and political aspects of information systems in the context of innovative applications. The course is designed as a series of case studies in information science, with presentations given by the people involved in designing or maintaining those systems. Examples include arXiv, NSDL, NuPrl, the Legal Information Institute, Protomap, Dspace, and others created or maintained at Cornell, as well as some representative exterior resources. The case studies are augmented by readings and discussions of recent articles on technical components of the information systems, including machine learning tools, link and network analysis, metadata standards, document formats and clustering, data integrity, and natural language processing. Aspects of human and social interactions with the information systems considered include copyright issues, privacy issues, public/private partnerships, and publishing models.

**INFO 440 Advanced Human-Computer Interaction Design (also COMM 440)**
Fall. 3 credits.
For description, see COMM 440.

**INFO 447 Social and Economic Data (also ILR 447)**
Spring. 4 credits. Prerequisites: one semester of calculus, the IS statistics requirement, at least one upper-level social science course, or permission of the instructor.
For description, see ILR 447.

**INFO 450 Language and Technology (also COMM 450)**
Spring. 3 credits.
For description, see COMM 450.

**INFO 490 Independent Reading and Research**
Fall, spring. 1–4 credits.
Independent reading and research for undergraduates.

**INFO 491 Teaching in Information Science, Systems, and Technology**
Fall, spring. Variable credit.
This course involves working as a T.A. in a course in the information science, systems, and technology major.

**INFO 515 Culture, Law, and Politics of the Internet**
Fall. 4 credits.
This course explores the culture, law, and politics of the Internet. Free speech concerns, Internet governance, domain naming, copyright, privacy, and security are highlighted as well as a variety of policy issues such as acceptable-use bandwidth usage on campuses, protocols for DMCA compliance, and the balance of classroom and distributed learning.

**INFO 530 The Architecture of Large-Scale Information Systems (also COM S 530)**
Spring. 4 credits. Prerequisite: COM S/ INFO 330 or COM S 432.
For description, see COM S 530.

**INFO 614 Cognitive Psychology (also PSYCH 614)**
Fall. 5 credits. S. Edelman.
For description, see PSYCH 614.

**INFO 630 Representing and Accessing Digital Information (also COM S 630)**
Fall. 4 credits. Prerequisite: COM S 472 or 478 or 578 or the equivalent.
For description, see COM S 630.

**INFO 634 Information Technology in Sociocultural Context (also S&TS 634)**
Fall. 4 credits. Prerequisite: permission of instructor.
For description, see S&TS 634.

**INFO 635 Seminar on Applications of Information Science (also INFO 435)**
Spring. 3 credits. Prerequisites: background in computing, data structures, and programming at the level of COM S 211 or equivalent, and experience in using information systems.
For description, see INFO 435.

**INFO 640 Human-Computer Interaction Design (also COMM 640)**
Fall. 3 credits. Prerequisite: graduate standing or permission of instructor.
For description, see COMM 640.

**INFO 685 The Structure of Information Networks (also COM S 685)**
Spring. 4 credits. Prerequisite: COM S 482.
For description, see COM S 685.