Professor: Robert A. Beezer; James Bernhard, *Chair*; Sigrun Bodine (on leave fall 2019); Martin Jackson; Bradley Richards; Michael Spivey

Associate Professor: David Chiu; Adam Smith (on leave spring 2020)

Assistant Professor: America Chambers (on leave spring 2020); Jacob Price; Courtney Thatcher

Visiting Professor: Henry Walker

Visiting Assistant Professor: Xi Chen, Cynthia Gibson;

Instructor: Alison Paradise, Matthew Pickard

Visiting Instructor: Wendy Dove

About the Department

How does the human brain work? What does the future hold for our climate? Is it possible for a computer to understand natural language? How can we most efficiently and securely transmit information over the Internet? When is it useful to distinguish between different levels of infinity?

Mathematics and computer science provide the critical foundation required to answer some of the most pivotal and complex questions of our time. Mathematicians design the models that enable us to understand and improve the structure of transportation networks, computer networks and physical processes, making them more efficient, effective, and versatile. Whether or not practical applications are foreseen, mathematicians revel in exploring the structure and beauty of abstract patterns, logical relationships, and rigorous formal proofs. Computer scientists build the invisible layer of software that drives significant advances in scientific research and improves everyday life. The newest smart phones are driven by tens of millions of lines of computer code, while a modern automobile includes over one hundred million lines of code—every aspect of which we depend upon for our productivity and safety.

To equip students with the conceptual knowledge to tackle such problems, the curriculum for the Department of Mathematics and Computer Science stresses the development of problem-solving techniques, logical reasoning, and data analysis. Special emphasis is placed on the value of abstraction: the process of simplifying a messy real-world problem to focus on the relevant details. Consistent with the university's core curriculum, the department provides a learning environment that encourages both independent thinking and group collaboration. Communication is of paramount importance; students learn to clearly articulate the nature of the problem, the analysis process, and the solution. Students who choose to study mathematics join a discipline that has been an important part of society for at least four thousand years. The foundation for a major in mathematics is formed by completing a sequence of three courses in calculus, and a course in linear algebra. Of calculus, Morris Kline wrote, "Following hard on the adoption of the function concept came the calculus, which, next to Euclidean geometry, is the greatest creation of all of mathematics." Linear algebra shares in the beauty, power and applicability of the calculus by providing a rich theory for modeling real-world phenomena by means of systems of linear equations. Building upon this foundation, students can select from a number of upper-division mathematics courses that broaden and deepen their understanding of mathematics, exploring areas such as abstract algebra, real and complex analysis, probability and statistics, mathematical modeling, and optimization.

Students studying computer science begin by learning how to write computer programs, but computer science is far more than just programming. Among other pursuits, computer scientists design and study algorithms (computational problem solving strategies) to solve difficult real-world problems, learn software engineering patterns to break down large projects into manageable pieces, and study the design of programming languages themselves. Those choosing to major or minor in computer science will have the opportunity to explore a rich set of elective courses, including artificial intelligence, computer graphics, database management systems, networks, and operating systems. For students with an interest in business, there is also an option to pursue an interdisciplinary Bachelor of Science degree in Computer Science and Business.

Students majoring in either mathematics or computer science will have the opportunity to join a strong community, through participation in a variety of student-initiated and faculty-sponsored groups. The department hosts a student-run Mathematics Club (first begun in 1927), and offers two faculty-guided problem-solving seminars preparing students to compete in the annual Mathematical Contest in Modeling (MCM) and Putnam contests. The department also features a local chapter of the Association of Computing Machinery (ACM) and a computer game development club, in which artists and computer science students are teaming up to create a new computer game.

The study of mathematics and computer science prepares students to enter a world in which computational and mathematical literacy are crucial. Many of our students move on to graduate study, and ultimately pursue careers in business, research, industry, education, government, and actuarial work, among others. Whether considering a major in mathematics or computer science, building the foundation for another discipline, or simply developing the quantitative literacy required to interact in an increasingly quantitative world, the Department of Mathematics and Computer Science provides the strategies and conceptual understanding to help students reach these goals.

Students who graduate from the Department of Mathematics and Computer Science will be able to communicate precisely in the formal language of mathematics or computer science, both verbally and in written form, work effectively individually and as part of a team, and leverage the power of abstraction to transform complex problems into simpler but conceptually relevant ones.

Additionally, students completing a degree in mathematics will be able to:

- Demonstrate an understanding of the core ideas in calculus and linear algebra, as well as a breadth or depth of understanding in other mathematical subject areas;
- Write clear and correct mathematical proofs;
- Successfully transition to advanced study in any of a range of pure or applied mathematical subject areas.

Computer science graduates will additionally be able to:

- Choose and apply appropriate algorithms and data structures to solve a problem;
- Analyze the correctness, efficiency, and viability of algorithms;
- Implement and evaluate complex software systems using a variety of tools.

General Requirements for the Major or Minor

General university degree requirements stipulate that 1) at least four units of the major or three units of the minor be taken in residence at Puget Sound; 2) students earn a GPA of 2.0 in courses taken for the major or the minor; and 3) all courses taken for a major or minor must be taken for graded credit. Any exceptions to these stipulations are indicated in the major and minor degree requirements listed below.

The Department of Mathematics and Computer Science offers courses cross-listed as both Mathematics and Computer Science as indicated

in their course descriptions. A student majoring or minoring in both Mathematics and Computer Science may apply only one such course to both majors, to both the major and the minor, or to both minors.

The Bachelor of Science in Mathematics

The department offers two options for a Bachelor of Science in Mathematics: a contract major and a standard major. The contract major emphasizes the value of planning a coherent set of courses based on goals and interests articulated by the student. The contract major also allows the flexibility of including a course from another department if the course has sufficient mathematical content and relates to the student's interests. The standard major is available for those students who declare a mathematics major later in their undergraduate career.

Contract option for the Bachelor of Science in Mathematics

This degree is awarded on the basis of a course of study agreed upon by the student and a committee of faculty members. A student who intends to complete a contract major in Mathematics should select a faculty member in the Department of Mathematics and Computer Science as an advisor. The student and advisor form a committee that consists of one additional faculty member from the Department of Mathematics and Computer Science and, if a course from another department is to be part of the contract, a faculty member from that department. The student works with the committee to select a coherent set of courses (satisfying the requirements given below) that advances the student's educational goals. The contract is signed by the student, committee members, and chair of the department, and is filed in the Office of the Registrar. The student can later modify the contract with the approval of all committee members and the department chair.

Each contract course of study will meet the following requirements.

1. Completion of a minimum of eight units and a maximum of 16 units with no more than nine units in mathematics.
2. Completion of CSCI 161 or equivalent.
3. Completion of a minimum of five upper-division units in mathematics to include the following:
   a. Two units of related upper-division courses chosen to provide depth.
   b. One upper-division unit in a proof-based course.

   Courses must be approved by the end of the semester in which the first upper-division course on the contract is completed. Upper-division courses completed before the contract is approved cannot be included in the contract.

Standard option for the Bachelor of Science in Mathematics

This degree is awarded on the basis of a course of study that meets the following requirements.

1. Completion of the calculus sequence (through MATH 280) and MATH 290.
2. Completion of CSCI 161 or equivalent.
3. Completion of five upper-division units in mathematics to include the following:
   a. Two units of related upper-division courses chosen to provide depth.
   b. One upper-division unit in a proof-based course.
   c. At least one upper-division unit from each of the following two lists to provide breadth of experience in both continuous and discrete mathematics:
      List A: MATH 301, 302, 350, 355, 360, 375, 376, 380, 420 (some topics as noted in topic course descriptions) 480, 481
      List B: MATH 300, 310, 335, 338, 340, 345, 390, 420 (some topics as noted in topic course descriptions), 471, 490, 491

Individual classes can count for more than one requirement in 3.

Notes for contract and standard majors

1. For the purposes of major requirements, upper-division courses in mathematics are those at the 300–400 level.
2. A student majoring in mathematics must earn a grade point average of at least 2.00 in all upper-division major courses.
3. A student majoring in mathematics must complete at least four units of the required upper-division courses in the major at Puget Sound. One of these four units may be a course taken as part of a study-abroad program. For contract majors, this is subject to approval in advance by the student's contract committee.
4. Contracts normally include the calculus sequence and linear algebra.
5. Currently-offered sets of related upper-division courses to provide depth in contract and standard majors include MATH 301/302, 335/471, 340/345, 350/355, 375/376, 480/481, 490/491.
6. Students majoring in mathematics should take CSCI 161 in their first two years.
7. Upper-division units must be approved by the end of the semester in which the first upper-division course on the contract is completed. Upper-division courses completed before the contract is approved cannot be included in the contract.

Requirements for the Minor in Mathematics

1. Completion of five units in mathematics, two of which must be numbered 170 or higher.
   a. MATH 103 and MATH 110 do not count toward a minor in mathematics.
   b. One unit of credit taken from Computer Science, either 141 or a course numbered 161 or higher, may count toward the minor and, if it is numbered 200 or higher, may count as one of the mathematics courses numbered 170 or higher.
   c. HON 213 may count toward the 170-level requirement.
   d. PHIL 240 may count toward the minor. It will not count as one of the required mathematics courses numbered 170 or higher.
   e. First-year Seminars do not meet the requirements of the minor.
2. Maintain a cumulative grade-point average of 2.0 in the five units.

The Bachelor of Science in Computer Science

The department offers two options for a Bachelor of Science in Computer Science: a contract major and a standard major. The contract major emphasizes the value of planning a coherent set of courses based on goals and interests articulated by the student. The contract major also allows the flexibility of including a course from another department if the course has sufficient computer science content and relates to the student's interests. The standard major is available for those students who declare a computer science major later in their undergraduate career.

Contract option for the Bachelor of Science in Computer Science

This degree is awarded on the basis of a course of study agreed upon by the student and a committee of faculty members. A student who intends to complete a contract major in Computer Science should select a faculty member in the Department of Mathematics and Computer Science as an advisor. The student and advisor form a committee that consists of one additional faculty member from the Department of Mathematics and Computer Science and, if a course from another department is to be part of the contract, a faculty member from that department. The student works with the committee to select a coherent set of courses (satisfying the

requirements given below) that advances the student's educational goals. The contract is signed by the student, committee members, and chair of the department, and is filed in the Office of the Registrar. The student can later modify the contract with the approval of all committee members and the department chair.

Each contract course of study will meet the following requirements.

1. Completion of a minimum of eight units and a maximum of 16 units with no more than 10 units in computer science.
2. Completion of the sequence CSCI 161, 261, 361.
3. Completion of MATH 210. MATH 290 and an upper-division mathematics course from List B may be substituted for MATH 210 if the student earns a C or higher in both courses.
4. Completion of a minimum of five upper-division units in computer science. One of these may be from a field other than computer science provided the course has sufficient computer science content. The upper-division courses are to include at least two proof-based or writing courses in computer science.
5. Approval by the end of the semester in which the first upper-division course on the contract is completed. Upper-division courses completed before the contract is approved cannot be included in the contract.

Standard option for the Bachelor of Science in Computer Science

This degree is awarded on the basis of a course of study that meets the following requirements.

1. Completion of the sequence CSCI 161, 261, 240, 281.
2. Completion of CSCI 291, 361, and 475. MATH 290 and an upper-division mathematics course from List B may be substituted for MATH 210 of the student earns a C or higher in both courses.
3. Completion of MATH 210. MATH 290 and an upper-division mathematics course from List B may be substituted for MATH 210 if the student earns a C or higher in both courses.
4. Completion of two upper-division electives.
5. Completion of the Capstone CSCI 440.

Notes for contract and standard majors

1. For the purposes of major requirements, upper-division courses in computer science are those at the 300-400 level.
2. A student majoring in computer science must earn a grade point average of at least 2.00 in all upper-division major courses.
3. A student majoring in computer science must complete at least three units of the required upper-division courses for the major at Puget Sound. One of these three units may be a course taken as part of a study abroad program. For contract majors, this is subject to approval in advance by the student's contract committee.
4. Students majoring in computer science are encouraged to take MATH 210 in the first two years.
5. In lieu of the MATH 210 requirement for the computer science major, the department will allow the following two-course substitution:
   a. Completion of MATH 290 with a grade of C or better, and
   b. Completion of a 300-level or 400-level mathematics course from List B with a grade of C or better.

Requirements for the Minor in Computer Science

1. Two units to include CSCI 161, 261.
2. Three units from CSCI 240, 281, 291, 310, 315, 325, 335, 361, 370, 425, 431, 455, 475, 481, MATH 210. MATH 290 and an upper-division mathematics course from List B may be substituted for MATH 210 if the student earns a C or higher in both courses.

Note: Although there is no time restriction on when a course taken in the past can apply to a major or minor, students who plan to use a course taken several years ago as a prerequisite for a current course should consult the instructor to determine if they are adequately prepared.

Course Offerings in Mathematics and Computer Science

Unless otherwise specified, each course carries 1 unit of credit and is offered at least once each academic year. Please see "Frequency of Course Offerings" on page 10.

Note: Students must earn a grade of C- or better in all prerequisite courses.

Other courses offered by Mathematics and Computer Science Department faculty.

HON 213 Mathematical Reasoning: Foundations of Geometry
Satisfies the Mathematical Approaches core requirement.

Course Offerings in Mathematics

103 Introduction to Contemporary Mathematics This course provides an introduction to contemporary mathematics and its applications. It may include topics from management science, statistics, social choice, the geometry of size and shape, and mathematics for computer science. These topics are chosen for their basic mathematical importance and for the critical role their application plays in a person's economic, political, and personal life. This course is designed to be accessible even to students with a minimal background in mathematics. This course is not designed to prepare students for further work in mathematics. No credit will be given for MATH 103 if the student has prior credit for another mathematics course that is equivalent to any of our courses numbered Math 110 or higher. Unlike most other introductory mathematics classes, this course is not a requirement for any currently offered major. Therefore, students are advised not to take this class before deciding on a major. *Prerequisite: One year of high school mathematics. Satisfies the Mathematical Approaches core requirement. Offered Spring term only.*

110 Pre-Calculus This course presents the basic concepts of algebra and trigonometry needed for future courses in mathematics, science, business, or the behavioral and social sciences. It includes a review of elementary algebra, introduction to algebraic functions, exponential and logarithmic functions, and trigonometric functions. *Prerequisite: Three years of high school mathematics. Does **not** satisfy the Mathematical Approaches core requirement. Offered Fall term only.*

150 Finite Mathematics This course provides an introduction to the theory of linear systems and discrete probability with applications from business and the physical and social sciences. The study of linear systems includes a discussion of matrix theory and linear programming. The concepts from linear systems and probability are integrated in the study of Markov Chains and Game Theory. This course contains topics of particular interest to students studying business or business-related topics. It is an excellent choice for such students who are also seeking a minor in mathematics. *Prerequisite: three years of high school mathematics. Satisfies the Mathematical Approaches core requirement. Offered Spring term only.*

160 Introduction to Applied Statistics This course provides an introduction to statistics, concentrating on statistical concepts and the "why and when" of statistical methodology. The course focuses on learning to ask appropriate questions, collect data effectively, summarize and

interpret information, and understand the limitations of statistical inference. Students with Advanced Placement credit for MATH 160 should consider enrolling in MATH 260. *Prerequisite: three years of high-school mathematics. Satisfies the Mathematical Approaches core requirement.*

170 Calculus for Business, Behavioral, and Social Sciences This course takes a problem-solving approach to the concepts and techniques of single variable differential calculus, with an introduction to multivariate topics. Applications are selected primarily from business and the behavioral and social sciences. Students will not receive credit for MATH 170 if they have already taken MATH 180, MATH 181 and/or MATH 280, without prior permission of the department. This course is not intended for mathematics majors, but is a recommended course for students going on to graduate school in business, some social sciences, or desiring more quantitative courses in their studies. *Prerequisite: Three years of high school mathematics. Satisfies the Mathematical Approaches core requirement. Offered Spring term only.*

180 Calculus and Analytic Geometry I There are two main topics in the calculus for functions of one variable: differentiation and integration. This course focuses on differentiation starting with limits and continuity, then introduces the derivative, and applications of the derivative, in a variety of contexts. The course concludes with an introduction to integration. The central ideas are explored from the symbolic, graphic, numeric, and physical model points of view. *Prerequisite: MATH 110, or its equivalent. Satisfies the Mathematical Approaches core requirement.*

181 Calculus and Analytic Geometry II This course is a continuation of MATH 180. It focuses on integration and its relation to differentiation. Topics include definite integrals, antiderivatives, the Fundamental Theorems of Calculus, applications of integration, sequences, and series. The central ideas are explored from the symbolic, graphic, numeric, and physical model points of view. *Prerequisite: MATH 180 or its equivalent. Satisfies the Mathematical Approaches core requirement.*

210 Introduction to Mathematics of Computer Science An introduction to the mathematics underlying computer science. Topics include a review of basic set theory, logic (propositional and predicate), theorem proving techniques, logic as a method for representing information, equivalence relations, induction, combinatorics, graph theory, formal languages, and automata. *Prerequisite: CSCI 161.*

260 Intermediate Applied Statistics This course covers the fundamentals of conducting statistical analyses, with particular emphasis on regression analysis and linear models. Students learn to use sophisticated computer software as a tool to analyze and interpret data. *Prerequisite: MATH 160, MATH 181, PSYC 201, Advanced Placement Statistics, or the equivalent of one of these. Satisfies the Mathematical Approaches core requirement.*

280 Multivariate Calculus This course, a continuation of the calculus sequence that starts with MATH 180 and 181, is an introduction to the study of functions that have several variable inputs and/or outputs. The central ideas involving these functions are explored from the symbolic, the graphic, and the numeric points of view. Visualization and approximation, as well as local linearity continue as key themes in the course. Topics include vectors and the basic analytic geometry of three-space; the differential calculus of scalar-input, vector-output functions; the geometry of curves and surfaces; and the differential and integral calculus of vector-input, scalar-output functions. *Prerequisite: MATH 181 or its equivalent. Satisfies the Mathematical Approaches core requirement.*

290 Linear Algebra This course is a study of the basic concepts of linear algebra, and includes an emphasis on developing techniques for proving theorems. Students explore systems of linear equations, matrices, vector spaces, bases, dimension, linear transformations, determinants, eigenvalues, change of basis, and matrix representations of linear transformations. *Prerequisite: MATH 181. Satisfies the Mathematical Approaches core requirement. Also satisfies the Writing in the Discipline requirement.*

295 Problem Seminar No credit In this class students and faculty discuss problems that cut across the boundaries of the standard courses and investigate general strategies of problem solving. Students are encouraged to participate in a national mathematics competition. This class meets one hour a week, is graded only on a pass/fail basis, is a 0 credit course, and may be repeated. *Prerequisite: permission of instructor.*

296 Problem Seminar in Mathematical Modeling No credit Students are given examples of problems from an annual international mathematical modeling contest. The students, in groups and with faculty mentoring, develop approaches to the problems. The students and faculty also discuss winning solutions to the problems. The students are expected to participate in the contest and give a presentation of their solution. The course meets once per week, is graded on a pass/fail basis, is a 0 credit course, and can be repeated. *Prerequisite: MATH 280 and 290 or permission of the instructor.*

301 Differential Equations Ordinary differential equations (ODEs) are first introduced in the calculus sequence. This course provides a deeper look at the theory of ODEs and the use of ODEs in modeling real-world phenomena. The course includes studies of first order ODEs (both linear and nonlinear), second and higher order linear ODEs, and first order systems of ODEs (both linear and nonlinear). Existence and uniqueness of solutions is discussed in each setting. Most topics are viewed from a variety of perspectives including graphical, numerical, and symbolic. Tools and concepts from linear algebra are used throughout the course. Other topics that may be covered include series solutions, difference equations, and dynamical systems. *Prerequisite: MATH 280 and 290 or permission of the instructor. Offered every semester.*

302 Partial Differential Equations This course introduces partial differential equations, how they arise in certain physical situations, and methods of solving them. Topics of study include the heat equation, the wave equation, Laplace's Equation, and Fourier Series with its applications to partial differential equations and boundary value problems. Additional topics may include Green's Functions, the Fourier Transform, the method of characteristics, dispersive waves, and perturbation methods. *Prerequisite: MATH 301 or equivalent. Offered Fall term only.*

310 Numerical Analysis Students learn about numerical solutions to linear systems; numerical linear algebra, polynomial approximations (interpolation and extrapolation); numerical differentiation and integration. Students also learn about error analysis and how to select appropriate algorithms for specific problems. Prerequisite: Math 280, 290, and CSCI 161 or equivalent.

335 Optimization This course is about how to find the best, or at least good, solutions to large problems frequently arising in business, industrial, or scientific settings. Students learn how to model these problems mathematically, algorithms for finding solutions to them, and the theory behind why the algorithms work. Topics include the simplex method, duality theory, sensitivity analysis, and network models. The focus is on linear models and models with combinatorial structure, but some nonlinear models are considered as well. Optimization software is used frequently. Crosslisted as CSCI 335. *Prerequisite: MATH 280, 290, CSCI 161. Crosslisted with CSCI 310. Offered every other year.*

340 Combinatorics This course entails study of the basic principles of combinatorial analysis. Topics include combinations, permutations, inclusion-exclusion, recurrence relations, generating functions, and graph theory. Additional material may be chosen from among the following topics: Latin squares, Hadamard matrices, designs, coding theory, and combinatorial optimization. Satisfies the proof-based requirement in the mathematics major. *Prerequisite: MATH 290. Offered every other year, alternating with Math 345, Number Theory.*

345 Number Theory This course entails the study of the properties of numbers, with emphasis on the positive integers. Topics include divisibility, factorization, congruences, prime numbers, arithmetic functions, quadratic residues, and Diophantine equations. Additional topics may include primitive roots, continued fractions, cryptography, Dirichlet series, binomial coefficients, and Fibonacci numbers. Satisfies the proof-based requirement in the mathematics major. *Prerequisite: MATH 290. Offered every other year, alternating with Math 340 Conbinatorics.*

350 Topology This course covers the basics of point-set topology. The course focuses on what type of structures need to be placed on a set in order to make it a "topological space" and what properties are deduced from these structures. Topics include open and closed sets, continuity, compactness, connectedness, and a selection of topics from metric spaces, manifolds, functions spaces or quotient spaces. Satisfies the proof-based requirement in the mathematics major. *Prerequisite: MATH 290. Offered every other year, alternating with Math 355.*

355 Differential Geometry This course is an introduction to the application of calculus and linear algebra to the geometry of curves and surfaces. Topics include the geometry of curves, Frenet formulas, tangent planes, normal vectors and orientation, curvature, geodesics, metrics, and isometries. Additional topics may include the Gauss-Bonnet Theorem, minimal surfaces, calculus of variations, and hyperbolic geometry. After completion, students will have the background to begin studying further mathematical and theoretical physics topics such as Riemannian geometry, differential topology, general relativity, and gauge theory. Students will additionally develop their mathematical intuition and ability to use calculations and proofs to verify theorems and solve problems. Satisfies the proof-based requirement in the major contracts and the standard major. *Prerequisites: MATH 280 and 290 and grade of C- or higher. Offered every other year.*

360 Advanced Applied Statistics This course covers advanced methods in applied statistics, beyond those of Mathematics 260. The emphasis is on applied aspects of generalized linear models, which provide a framework for analyzing some types of data for which ordinary linear models are not suitable. The analyses will be conducted using R, so students entering the course should already have a working knowledge of R. Topics other than generalized linear models are included as time allows, such as: time series analysis, categorical data analysis, and statistical graphics. *Prerequisite: Math 260, the equivalent, or permission of the instructor. Offered every other year, alternating with MATH 376.*

375 Probability Theory and its Applications This course provides an introduction to the standard topics of probability theory, including probability spaces, random variables and expectations, discrete and continuous distributions, generating functions, independence and dependence, special probability models, sampling distributions, laws of large numbers, and the central limit theorem. The course emphasizes modeling real-world phenomena throughout. *Satisfies the proof-based requirement in the mathematics major. Prerequisite: MATH 280 and 290. Offered Fall term.*

380 Complex Analysis The calculus of functions with complex numbers as inputs and outputs has surprising depth and richness. The basic theory of these functions is developed in this course. The standard topics of calculus (function, limit, continuity, derivative, integral, series) are explored in this new context of complex numbers leading to some powerful and beautiful results. Applications include using conformal mappings to solve boundary-value problems for Laplace's equation. Satisfies the proof-based requirement in major contracts and the standard major. *Prerequisite: MATH 280 and 290 or permission of the instructor. Offered every other year.*

376 Mathematical Statistics This course introduces the theory of linear regression and uses it as a vehicle to investigate the mathematics behind applied statistics. The theory combines probability theory and linear algebra to arrive at commonly used results in statistics. The theory helps students understand the assumptions on which these results are based and decide what to do when these assumptions are not met, as it usually the case in applied statistics. *Satisfies the proof-based requirement in the mathematics major. Prerequisite: Math 375 or equivalent. Offered every other year, alternating with MATH 360.*

355 Differential Geometry This course is an introduction to the application of calculus and linear algebra to the geometry of curves and surfaces. Topics include the geometry of curves, Frenet formulas, tangent planes, normal vectors and orientation, curvature, geodesics, metrics, and isometries. Additional topics may include the Gauss-Bonnet Theorem, minimal surfaces, calculus of variations, and hyperbolic geometry. After completion, students will have the background to begin studying further mathematical and theoretical physics topics such as Riemannian geometry, differential topology, general relativity, and gauge theory. Students will additionally develop their mathematical intuition and ability to use calculations and proofs to verify theorems and solve problems. Satisfies the proof-based requirement in the major contracts and the standard major. *Prerequisites: MATH 280 and 290 and grade of C- or higher. Offered every other year.*

390 Advanced Linear Algebra This course begins as a review and continuation of MATH 290: Linear Algebra. Topics covered include invariant subspaces, Jordan canonical form, and rational canonical forms of linear transformations. The remainder of the course is split between advanced topics and applications. Advanced topics include decompositions (such as the LU decomposition), principal axis theorem, alternate definitions of the determinant, singular values, and quadratic forms. Applications include topics such as least-squares fit, error-correcting codes, linear programming, physical problems employing eigenvalues, Markov chains, and secret sharing. *Prerequsite: MATH 290.*

420 Advanced Topics in Mathematics This course allows students to explore mathematical topics beyond those covered in the standard mathematics curriculum. Some semester-long topics include combinatorics, number theory, numerical analysis, and topology. See the department website for further information on topics to be offered during the next two years, including the prerequisites for each topic. *The course may be repeated on a different topic for credit. Prerequisites vary with topic. Offered occasionally.*

471 Mathematical Modeling A study of the process of mathematical modeling as well as specific deterministic (both discrete and continuous) and stochastic models. Certain mathematical topics such as graph theory are developed as needed. *Prerequisite: CSCI 161, MATH 280 and 290; MATH 375 recommended. Offered every other year.*

480/481 Real Analysis I, II This course provides a rigorous study

of calculus. The course begins with a study of the real numbers and then moves on to the core topics of limits, continuity, differentiation, integration, and series. In the first semester, the focus is on functions of one variable; in the second semester, the focus is on scalar- and vector-valued functions of several variables. Additional topics may include differential geometry of curves and surfaces or vector calculus. Satisfies the proof-based requirement in major contracts and standard major. *Prerequisite: MATH 280 and 290 or equivalents, MATH 321 for 322. MATH 321 offered Fall term only; MATH 322 offered Spring term only.*

491/491 Abstract Algebra I, II These courses present a rigorous treatment of modern algebra. The writing of proofs is emphasized. Modern applications of abstract algebra to problems in chemistry, art, and computer science show that this is a contemporary field in which important contributions are currently being made. Topics include groups, rings, integral domains, field theory, and the study of homomorphisms. Applications such as coding theory, public-key cryptography, crystallographic groups, and frieze groups may be covered. *These are proof-based courses. Satisfies the proof-based requirement in major contracts and the standard major. Prerequisite: MATH 290 or permission of the instructor. MATH 433 offered Fall term only. MATH 434 offered Spring term only.*

492/493 Senior Thesis Credit, variable up to one unit. A senior thesis allows students to explore areas of mathematics that are new to them, to develop the skill of working independently on a project, and to synthesize and present a substantive work to the academic community. Thesis proposals are normally developed in consultation with the student's research committee. This committee consists of the student's faculty supervisor and two other faculty members. It is involved in the final evaluation of the project. The results are presented in a public seminar or written in a publishable form. *Prerequisite: Completion of at least 4 upper-division (300-400 level) courses by the end of the junior year, or completion of the major by the end of the fall term of the senior year. The student should have a grade point average of at least 3.5 in all major courses numbered 300 or above.*

495/496 Independent Study Credit variable up to 1 unit. Students wishing to study an academic area not covered by existing courses in the curriculum may take an independent study. Students should obtain a copy of the *Independent Study Policy* from the Office of the Registrar. *Prerequisite: Junior or senior class standing and cumulative grade-point average of 3.0.*

Course Offerings in Computer Science

Note: Students must obtain a grade of C- or better in all prerequisite courses.

141 Programming for Natural Sciences This course is an introduction to computer science and programming intended for students in the natural sciences. The emphasis is on problems that might come up in a modern research laboratory. Assignments and exercises are done in Python programming language, which is favored by many natural scientists. The course teaches how to maintain an electronic notebook of calculations, to complement the traditional lab notebook. There is also a focus on standard data structures and good programming techniques, giving the student a solid grounding in modern programming techniques. *Students who receive credit for CSCI 161 or 261 will not receive credit for 141. Prerequisite: MATH 110 or three years of high school math.*

161 Introduction to Computer Science This course is an introduction to computer science and programming. The programming language Java is used to illustrate concepts in computer science. The course emphasizes the use of the computer as a problem-solving tool and the development of good programming style. CSCI 161 is the introductory course for students planning to major or minor in computer science. A weekly laboratory is required. *Prerequisite: three years of high-school mathematics, MATH 110, or equivalent. Satisfies the Mathematical Approaches core requirement.*

240 Software Engineering Students study the design and implementation of large software systems. Topics include design methodologies, programming team organization, and management, program verification and maintenance, design patterns and software engineering tools. *Prerequisite: CSCI 261 with a grade of C- or better. Satisfies a writing requirement in major contracts.*

261 Computer Science II This course is a continuation of CSCI 161. It provides an introduction to the study of fundamental data structures and their associated algorithms. Students learn how to choose appropriate data structures and algorithms for particular problems. They learn about lists, stacks, queues, trees, sorting, searching, abstract data types, and object-oriented programming using an object-oriented programming language. A weekly laboratory is required. *Prerequisite: CSCI 161 or permission of instructor. Satisfies the Mathematical Approaches core requirement.*

281 Assembly Language and Computer Architecture Introduction to machine organization, machine structure, data representation, digital logic, and assembly language programming on a RISC based architecture. *Prerequisite: CSCI 261. Offered frequently.*

291 Programming Language Paradigms Declarative programming languages are an important alternative to languages (such as C, C++, and Java) that use the more familiar imperative programming paradigm. This course introduces the functional, dataflow, and logic programming paradigms in depth through assignments in the programming languages Haskell and Prolog. These languages are based on models of computation that are fundamentally different from the von Neumann model underlying imperative programming languages, and exposure to these new paradigms provides valuable perspective on programming and problem solving in general. *Prerequisite: CSCI 261. Offered frequently.*

295 Problem Seminar No credit Consideration of a diverse range of problems in computer science from problems in the design of correct and efficient algorithms and the implementation of data structures through problems in the theory of computation. *Prerequisite: CSCI 261 recommended. Offered frequently.*

310 Numerical Analysis Students learn about numerical solutions to linear systems; numerical linear algebra, polynomial approximations (interpolation and extrapolation); numerical differentiation and integration. Students also learn about error analysis and how to select appropriate algorithms for specific problems. Crosslisted with MATH 310. *Prerequisite: Math 280, 290, and CSCI 161 or equivalent.*

315 Computer Graphics This course is an introduction to the process of generating images with a computer. The emphasis is on the design and use of graphical facilities for two- and three-dimensional graphics. Students study the mathematical theory underlying computer generated graphics, and will implement programs utilizing these techniques. The mathematical topics covered include rotations, translations, and perspective. The core pieces of the graphics pipeline used in current graphics hardware are studied. *Prerequisite: CSCI 261. Offered frequently.*

325 Network Programming Computer networks have become a

fundamental part of our everyday lives—used for everything from social networking to research and commerce. This course introduces the concepts behind modern computer networks and their implementation. It covers the software and hardware architecture of the internet, networking protocols like TCP and IP, how services like Email and the Web work, approaches for reliable and secure communication, and the details of both wired and wireless transmission. Programming exercises in Java and C++ will reinforce key concepts form the course. *Prerequisite: CSCI 240. Offered frequently.*

335 Optimization This course is about how to find the best—or at least good—solutions to large problems frequently arising in business, industrial, or scientific settings. Students learn how to model these problems mathematically, algorithms for finding solutions to them, and the theory behind why the algorithms work. Topics include the simplex method, duality theory, sensitivity analysis, and network models. The focus is on linear models and models with combinatorial structure, but some nonlinear models are considered as well. Optimization software is used frequently. *Crosslisted as MATH 335. Prerequisite: MATH 280, 290, CSCI 161. Offered every other year.*

361 Algorithms and Data Structures This is a course in advanced data structures, the algorithms needed to manipulate these data structures, proofs that the algorithms are correct, and a runtime analysis of the algorithms. Students study advanced data structures such as Red-Black Trees, 2-3 Trees, Heaps, and Graphs. Students also study algorithm design techniques including Greedy Algorithms, Divide and Conquer, Dynamic Programming, and Backtracking. They also learn about NP-Complete problems. *Satisfies a writing requirement in major contracts. Prerequisite: CSCI 261, 281 (may be taken concurrently), and MATH 210. Offered frequently.*

370 Theory of Computation An introduction to formal models of computers and computation. Topics include formal languages and automata theory, computability, decidability, and Church's Thesis. Satisfies the proof-based requirement in major contracts and the standard major. *Prerequisite: CSCI 361 and MATH 210. Offered occasionally.*

425 Advanced Topics in Computer Science The topics are chosen each time the course is offered to meet the interests of students and instructors. Possible topics include computer architecture, computer modeling and simulation, networks, advanced graphics, and advanced artificial intelligence. *Prerequisite: CSCI 361 and permission of the instructor. Offered occasionally.*

431 Introduction to Artificial Intelligence This course introduces the student to the techniques of artificial intelligence. Students learn strategies for uninformed and informed (heuristic) search, knowledge representation, problem-solving, and machine learning. Additional topics may include motion planning, probabilistic reasoning, natural language understanding, and philosophical implications. *Prerequisite: CSCI 361 (may be taken concurrently) and MATH 180, or permission of the instructor. Offered frequently.*

440 Capstone in Computer Science The senior capstone course provides computer science majors the opportunity to integrate the knowledge that they have gained from across the curriculum. Students are encouraged to work in teams, and can pursue either an applied or theory project. Students choosing applied projects participate in the identification of a problem, develop a project proposal outlining an approach to the problem's solution, implement the proposed solution, and test or evaluate the result. Students choosing a theory project conduct original research (e.g., develop a new algorithm) and evaluate its strengths and limitations. Regardless of the choice of project, students document their work in the form of written reports and oral presentations. *Prerequisite: Senior class standing, CSCI 240, CSCI 361, or permission of instructor. Offered Spring term only.*

455 Principles of Database Systems The management of data is one of the classical problems throughout the history of computing. This course centers around the fundamental concepts and theory that underpin the relational data model, which addresses numerous problems that plague data management, including data independence, consistency, information loss, and access performance. Course topics include the relational data model, database languages (e.g., SQL), relational database theory, database design (by decomposition), query execution, and considerations that affect system performance. Students design database schemas that effectively model an organization's information requirements and write programs that require database integration. Students also gain insight through the analysis and implementation of influential data structures and algorithms that are commonly used in modern relational database systems. *Prerequisite: CSCI 261; MATH 210 or instructor permission. Offered frequently.*

460/461/462 Senior Project 0.5 or 1 unit A practical computer software development experience to incorporate topics learned in advanced computer science courses with the tools and techniques for software development studied in the software engineering class. Students may enroll in either the one-semester, one-unit 460 or the two-semester, 0.5 unit per semester sequence, but not both. *Satisfies a writing requirement in major contracts and the standard major. Prerequisite: CSCI 240, with at least one upper-division computer science course in an area related to the project.*

475 Operating Systems One the most complex software systems ever assembled, the modern operating system serves as the interface between the human and the machine. This course traces how the simple idea of ``resource sharing'' unravels into some of the most confounding problems and original breakthroughs in computer science. Course topics include process and thread management, input/output, CPU scheduling, synchronization primitives, memory management, and file systems. Students taking this course learn how to deal with the intricacies of low-level programming, parallel computing and synchronization problems, and also receive kernel-development experience through the design and implementation of various subsystems in a real operating system. The C programming language is used for homework assignments and projects. Prerequisite: CSCI 281. *Offered frequently.*

481 Compilers and Compiler Writing Compilers take input programs written in a high-level language and generate equivalent programs in a low-level language. This course introduces the mathematical tools (formal languages and automata) necessary for recognizing and validating input programs and the computational techniques used to construct equivalent output programs. Students develop first-hand experience with the process by implementing a sample compiler as a course project. The tools and techniques introduced in this course can be applied across a wide range of applications. In particular, this course is valuable preparation for writing any program that needs to read and act on structured input files. *Prerequisite: CSCI 281, 240, 281, and 361; CSCI 370 is recommended. Offered occasionally.*

491/492 Senior Thesis Credit, variable up to one unit A senior thesis allows students to explore areas of computer science that are new to them, to develop the skill of working independently on a project, and to synthesize and present a substantial work to the academic community. Thesis proposals are normally developed in consultation with the stu-

dent's research committee. This committee consists of the student's faculty supervisor and two other faculty members. It is involved in the final evaluation of the project. The results are presented in a public seminar or written in a publishable form. *Prerequisite: completion of at least 4 upper-division courses by the end of the junior year, or completion of the major by the end of the fall term of the senior year. The student should have a grade point average of at least 3.5 in all major courses numbered 300 or above.*

495/496 Independent Study Credit, variable up to 1 unit Students wishing to study an academic area not covered by existing courses in the curriculum may take an independent study. Students should obtain a copy of the *Independent Study Policy* from the Office of the Registrar. *Prerequisite: junior or senior class standing and cumulative grade-point average of 3.0.*