COMPUTER SCIENCE

Courses offered by the Department of Computer Science are listed under the subject code CS on the *Stanford Bulletin's* ExploreCourses web site.

The Department of Computer Science (CS) operates and supports computing facilities for departmental education, research, and administration needs. All CS students have access to the departmental student machine for general use (mail, news, etc.), as well as computer labs with public workstations located in the Gates Building. In addition, most students have access to systems located in their research areas.

Each research group in Computer Science has systems specific to its research needs. These systems include workstations (PCs, Macs), multi-CPU computer clusters, and local mail and file servers. Servers and workstations running Linux or various versions of Windows are commonplace. Support for course work and instruction is provided on systems available through U (http://itservices.stanford.edu)niversity IT (https://uit.stanford.edu) (UIT) and the School of Engineering (http://engineering.stanford.edu) (SoE).

Mission of the Undergraduate Program in Computer Science

The mission of the undergraduate program in Computer Science is to develop students' breadth of knowledge across the subject areas of computer science, including their ability to apply the defining processes of computer science theory, abstraction, design, and implementation to solve problems in the discipline. Students take a set of core courses. After learning the essential programming techniques and the mathematical foundations of computer science, students take courses in areas such as programming techniques, automata and complexity theory, systems programming, computer architecture, analysis of algorithms, artificial intelligence, and applications. The program prepares students for careers in government, law, and the corporate sector, and for graduate study.

Learning Outcomes (Undergraduate)

The department expects undergraduate majors in the program to be able to demonstrate the following learning outcomes. These learning outcomes are used in evaluating students and the department's undergraduate program. Students are expected to be able to:

1. Apply the knowledge of mathematics, science, and engineering.
2. Design and conduct experiments, as well to analyze and interpret data.
3. Design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
4. Function on multidisciplinary teams.
5. Identify, formulate, and solve engineering problems.
6. Understand professional and ethical responsibility.
7. Communicate effectively.
8. Understand the impact of engineering solutions in a global, economic, environmental, and societal context.
9. Demonstrate a working knowledge of contemporary issues.
10. Apply the techniques, skills, and modern engineering tools necessary for engineering practice.
11. Transition from engineering concepts and theory to real engineering applications.

Learning Outcomes (Graduate)

The purpose of the master's program is to provide students with the knowledge and skills necessary for a professional career or doctoral studies. This is done through course work in the foundational elements of the field and in at least one graduate specialization. Areas of specialization include artificial intelligence, biocomputation, computer and network security, human-computer interaction, information management and analytics, mobile and internet computing, real-world computing, software theory, systems, and theoretical computer science.

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship and the ability to conduct independent research. Through course work and guided research, the program prepares students to make original contributions in Computer Science and related fields.

Graduate Programs in Computer Science

The University's basic requirements for the M.S. and Ph.D. degrees are discussed in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees)" section of this bulletin.

Computer Science Course Catalog Numbering System

The first digit of a CS course number indicates its general level of sophistication:

Digit	Description
001-099	Service courses for nontechnical majors
100-199	Other service courses, basic undergraduate
200-299	Advanced undergraduate/beginning graduate
300-399	Advanced graduate
400-499	Experimental
500-599	Graduate seminars

The tens digit indicates the area of Computer Science it addresses:

Digit	Description
00-09	Introductory, miscellaneous
10-19	Hardware and Software Systems
20-39	Artificial Intelligence
40-49	Software Systems
50-59	Mathematical Foundations of Computing
60-69	Analysis of Algorithms
70-79	Computational Biology and Interdisciplinary Topics
90-99	Independent Study and Practicum

Bachelor of Science in Computer Science

The department offers both a major in Computer Science and a minor in Computer Science. Further information is available in the *Handbook for Undergraduate Engineering Programs* published by the School of Engineering. The Computer Science major offers a number of tracks (programs of study) from which students can choose, allowing them to focus their program on the areas of most interest. These tracks also reflect the broad diversity of areas in computing disciplines. The department has an honors program.

In addition to Computer Science itself, Stanford offers several interdisciplinary degrees with a substantial computer science component. The Symbolic Systems major (in the School of Humanities and Sciences) offers an opportunity to explore computer science and its relation to linguistics, philosophy, and psychology. The Mathematical and Computational Sciences major (also Humanities and Sciences) allows students to explore computer science along with more mathematics, statistics, and operations research.

Computer Science (CS)

Completion of the undergraduate program in Computer Science leads to the conferral of the Bachelor of Science in Computer Science.

Mission of the Undergraduate Program in Computer Science

The mission of the undergraduate program in Computer Science is to develop students' breadth of knowledge across the subject areas of computer science, including their ability to apply the defining processes of computer science theory, abstraction, design, and implementation to solve problems in the discipline. Students take a set of core courses. After learning the essential programming techniques and the mathematical foundations of computer science, students take courses in areas such as programming techniques, automata and complexity theory, systems programming, computer architecture, analysis of algorithms, artificial intelligence, and applications. The program prepares students for careers in government, law, the corporate sector, and for graduate study.

Requirements

Mathematics (26 units minimum)—

CS 103	Mathematical Foundations of Computing	5
CS 109	Introduction to Probability for Computer Scientists	5
MATH 19	Calculus [1]	3
MATH 20	Calculus [1]	3
MATH 21	Calculus [1]	4
Plus two electives [2]		

Science (11 units minimum)—

PHYSICS 41	Mechanics	4
PHYSICS 43	Electricity and Magnetism	4
Science elective [3]		3

Technology in Society (3-5 units)—

One course; course chosen must be on the SoE Approved Courses list at <ughb.stanford.edu> the year taken; see Basic Requirements 4 in the School of Engineering section

Engineering Fundamentals (13 units minimum; see Basic Requirement 3 in the School of Engineering section)—

CS 106B	Programming Abstractions	5
or CS 106X	Programming Abstractions (Accelerated)	
ENGR 40M	An Intro to Making: What is EE (or ENGR 40A and ENGR 40B)	3-5
Fundamentals Elective (May be an ENGR fundamentals or an additional CS Depth course. See Fig. 3-4 in the UGHB for approved ENGR fundamentals list. May not be any CS 106)		3-5
*Students who take ENGR 40A or 40M for fewer than 5 units are required to take 1-2 additional units of ENGR Fundamentals (13 units minimum), or 1-2 additional units of Depth (27 units minimum for track and elective courses).		

Writing in the Major—

Select one of the following:		
CS 181W	Computers, Ethics, and Public Policy	
CS 191W	Writing Intensive Senior Project	
CS 194W	Software Project	
CS 210B	Software Project Experience with Corporate Partners	
CS 294W	Writing Intensive Research Project in Computer Science	

Computer Science Core (15 units)—

CS 107	Computer Organization and Systems	5
or CS 107E	Computer Systems from the Ground Up	
CS 110	Principles of Computer Systems	5
CS 161	Design and Analysis of Algorithms	5

Senior Project (3 units)—

CS 191	Senior Project	
CS 191W	Writing Intensive Senior Project	
CS 194	Software Project	
CS 194H	User Interface Design Project	
CS 194W	Software Project	
CS 210B	Software Project Experience with Corporate Partners	
CS 294	[6]	
or CS 294W	Writing Intensive Research Project in Computer Science	

Computer Science Depth B.S.

Choose one of the following ten CS degree tracks (a track must consist of at least 25 units and 7 classes):

Artificial Intelligence Track—

		Units
CS 221	Artificial Intelligence: Principles and Techniques	4
Select two courses, each from a different area:		
Area I, AI Methods:		
CS 228	Probabilistic Graphical Models: Principles and Techniques	
CS 229	Machine Learning	
CS 234	Reinforcement Learning	
CS 238	Decision Making under Uncertainty	
Area II, Natural Language Processing:		
CS 124	From Languages to Information	
CS 224N	Natural Language Processing with Deep Learning	
CS 224S	Spoken Language Processing	
CS 224U	Natural Language Understanding	
Area III, Vision:		
CS 131	Computer Vision: Foundations and Applications	
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	
CS 231N	Convolutional Neural Networks for Visual Recognition	
Area IV, Robotics:		
CS 223A	Introduction to Robotics	
Select one additional course from the Areas above or from the following:		
AI Methods:		
CS 157	Logic and Automated Reasoning	

CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	
STATS 315A	Modern Applied Statistics: Learning	
STATS 315B	Modern Applied Statistics: Data Mining	
Vision:		
CS 231B		
CS 231M		
CS 331A		
Comp Bio:		
CS 262		
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	
CS 371	Computational Biology in Four Dimensions	
CS 374		
Information and the Web:		
CS 276	Information Retrieval and Web Search	
CS 224W	Analysis of Networks	
Other:		
CS 227B	General Game Playing	
CS 277		
CS 379	Interdisciplinary Topics	
Robotics and Control:		
CS 327A	Advanced Robotic Manipulation	
CS 329	Topics in Artificial Intelligence (with advisor approval)	
ENGR 205	Introduction to Control Design Techniques	
EE 209		
MS&E 251	Stochastic Control	
MS&E 351	Dynamic Programming and Stochastic Control	
Track Electives: at least three additional courses selected from the Areas and lists above, general CS electives, or the following: [4]		
CS 238	Decision Making under Uncertainty	
CS 275	Translational Bioinformatics	
CS 326	Topics in Advanced Robotic Manipulation	
CS 334A	Convex Optimization I	
or EE 364A	Convex Optimization I	
CS 428	Computation and cognition: the probabilistic approach	
EE 278	Introduction to Statistical Signal Processing	
EE 364B	Convex Optimization II	
ECON 286	Game Theory and Economic Applications	
MS&E 252	Decision Analysis I: Foundations of Decision Analysis	
MS&E 352	Decision Analysis II: Professional Decision Analysis	
MS&E 355	Influence Diagrams and Probabilistics Networks	
PHIL 152	Computability and Logic	
PSYCH 202	Cognitive Neuroscience	
PSYCH 204A	Human Neuroimaging Methods	
PSYCH 204B	Computational Neuroimaging: Methods & Analyses	
PSYCH 209	Neural Network Models of Cognition: Principles and Applications	
STATS 200	Introduction to Statistical Inference	
STATS 202	Data Mining and Analysis	
STATS 205	Introduction to Nonparametric Statistics	

Biocomputation Track—

		Units
The Mathematics, Science, and Engineering Fundamentals requirements are non-standard for this track. See Handbook for Undergraduate Engineering Programs for details.		
Select one of the following:		3-4
CS 221	Artificial Intelligence: Principles and Techniques	
CS 228	Probabilistic Graphical Models: Principles and Techniques	
CS 229	Machine Learning	
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	
Select one of the following:		
CS 262		
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	
CS 273A	The Human Genome Source Code	
CS 274	Representations and Algorithms for Computational Molecular Biology	
CS 275	Translational Bioinformatics	
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	
One additional course from the lists above or the following:		3-4
CS 124	From Languages to Information	
CS 145	Introduction to Databases	
CS 147	Introduction to Human-Computer Interaction Design	
CS 148	Introduction to Computer Graphics and Imaging	
CS 248	Interactive Computer Graphics	
One course selected from the following:		3-4
CS 108	Object-Oriented Systems Design	3-4
CS 124	From Languages to Information	3-4
CS 131	Computer Vision: Foundations and Applications	3-4
CS 140	Operating Systems and Systems Programming	3-4
or CS 140E	Operating systems design and implementation	
CS 142	Web Applications	3
CS 143	Compilers	3-4
CS 144	Introduction to Computer Networking	3-4
CS 145	Introduction to Databases	3-4
CS 147	Introduction to Human-Computer Interaction Design	3-5
CS 148	Introduction to Computer Graphics and Imaging	3-4
CS 149	Parallel Computing	3-4
CS 154	Introduction to Automata and Complexity Theory	3-4
CS 155	Computer and Network Security	3
CS 157	Logic and Automated Reasoning	3
or PHIL 151	Metalogic	
CS 164		
CS 166	Data Structures	3-4
CS 167		
CS 168	The Modern Algorithmic Toolbox	3-4
CS 190		
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	3
CS 205B	Mathematical Methods for Fluids, Solids, and Interfaces	3
CS 210A	Software Project Experience with Corporate Partners	3-4

CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 223A	Introduction to Robotics	3
CS 224N	Natural Language Processing with Deep Learning	3-4
CS 224S	Spoken Language Processing	2-4
CS 224U	Natural Language Understanding	3-4
CS 224W	Analysis of Networks	3-4
CS 225A	Experimental Robotics	3
CS 227B	General Game Playing	3
CS 228	Probabilistic Graphical Models: Principles and Techniques	3-4
CS 229	Machine Learning	3-4
CS 229T	Statistical Learning Theory	3
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	3-4
CS 231B		
CS 231M		
CS 231N	Convolutional Neural Networks for Visual Recognition	3-4
CS 232	Digital Image Processing	3
CS 233	Geometric and Topological Data Analysis	3
CS 234	Reinforcement Learning	3
CS 238	Decision Making under Uncertainty	3-4
CS 240	Advanced Topics in Operating Systems	3
CS 240H		
CS 242	Programming Languages	3
CS 243	Program Analysis and Optimizations	3-4
CS 244	Advanced Topics in Networking	3-4
CS 244B	Distributed Systems	3
CS 245	Database Systems Principles	3
CS 246	Mining Massive Data Sets	3-4
CS 247	Human-Computer Interaction Design Studio	3-4
CS 248	Interactive Computer Graphics	3-4
CS 249A		
CS 251	Bitcoin and Crypto Currencies	3
CS 254	Computational Complexity	3
CS 255	Introduction to Cryptography	3
CS 261	Optimization and Algorithmic Paradigms	3
CS 262		
CS 263	Algorithms for Modern Data Models	3
CS 264	Beyond Worst-Case Analysis	3
CS 265	Randomized Algorithms and Probabilistic Analysis	3
CS 266		
CS 267	Graph Algorithms	3
CS 269I	Incentives in Computer Science	3
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	3
CS 272	Introduction to Biomedical Informatics Research Methodology	3-5
CS 273A	The Human Genome Source Code	3
CS 273B	Deep Learning in Genomics and Biomedicine	3
CS 274	Representations and Algorithms for Computational Molecular Biology	3-4
CS 275	Translational Bioinformatics	4
CS 276	Information Retrieval and Web Search	3
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3
CS 348B	Computer Graphics: Image Synthesis Techniques	3-4
CS 348C	Computer Graphics: Animation and Simulation	3
CS 371	Computational Biology in Four Dimensions	3
CS 374		
CME 108	Introduction to Scientific Computing	3
EE 180	Digital Systems Architecture	4
EE 263	Introduction to Linear Dynamical Systems	3
EE 282	Computer Systems Architecture	3
EE 364A	Convex Optimization I	3
BIOE 101	Systems Biology	3
MS&E 152	Introduction to Decision Analysis	3-4
MS&E 252	Decision Analysis I: Foundations of Decision Analysis	3-4
STATS 206	Applied Multivariate Analysis	3
STATS 315A	Modern Applied Statistics: Learning	2-3
STATS 315B	Modern Applied Statistics: Data Mining	2-3
BMI 231		
BMI 260		
GENE 211	Genomics	3
One course from the following:		3-5
CS 145	Introduction to Databases	3-4
CS 147	Introduction to Human-Computer Interaction Design	3-5
CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 228	Probabilistic Graphical Models: Principles and Techniques	3-4
CS 229	Machine Learning	3-4
CS 262		
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	3
CS 273A	The Human Genome Source Code	3
CS 273B	Deep Learning in Genomics and Biomedicine	3
CS 274	Representations and Algorithms for Computational Molecular Biology	3-4
CS 275	Translational Bioinformatics	4
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3
CS 371	Computational Biology in Four Dimensions	3
CS 373	Statistical and Machine Learning Methods for Genomics	3
CS 374		
EE 263	Introduction to Linear Dynamical Systems	3
EE 364A	Convex Optimization I	3
MS&E 152	Introduction to Decision Analysis	3-4
MS&E 252	Decision Analysis I: Foundations of Decision Analysis	3-4
STATS 206	Applied Multivariate Analysis	3
STATS 315A	Modern Applied Statistics: Learning	2-3
STATS 315B	Modern Applied Statistics: Data Mining	2-3
BMI 231		
BMI 260		
GENE 211	Genomics	3
One course selected from the list above or the following:		
BIOE 222A		
BIOE 222B		
CHEMENG 150	Biochemical Engineering	3
CHEMENG 174	Environmental Microbiology I	3
APPPHYS 294	Cellular Biophysics	3
BIO 104	Advanced Molecular Biology	5
BIO 118	Genetic Analysis of Biological Processes	4

BIO 129A		
BIO 129B		
BIO 188		
BIO 189		
BIO 214	Advanced Cell Biology	4
BIO 217		
BIO 230	Molecular and Cellular Immunology	4
CHEM 135		
CHEM 171	Physical Chemistry I	4
BIOC 218		
BIOC 241	Biological Macromolecules	3-5
SBIO 228		
One course from the following:		
BIOE 220	Introduction to Imaging and Image-based Human Anatomy	3
BIOE 222A		
BIOE 222B		
CHEMENG 150	Biochemical Engineering	3
CHEMENG 174	Environmental Microbiology I	3
CS 262		
CS 274	Representations and Algorithms for Computational Molecular Biology	3-4
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3
CS 371	Computational Biology in Four Dimensions	3
CS 374		
ME 281	Biomechanics of Movement	3
APPHYS 294		
BIO 104	Advanced Molecular Biology	5
BIO 112	Human Physiology	4
BIO 118	Genetic Analysis of Biological Processes	4
BIO 129A		
BIO 129B		
BIO 158	Developmental Neurobiology	4
BIO 183	Theoretical Population Genetics	3
BIO 188		
BIO 189		
BIO 214	Advanced Cell Biology	4
BIO 217		
BIO 230	Molecular and Cellular Immunology	4
CHEM 135		
CHEM 171	Physical Chemistry I	4
BIOC 218		
BIOC 241	Biological Macromolecules	3-5
DBIO 210	Developmental Biology	4
GENE 211	Genomics	3
SBIO 228		
SURG 101	Regional Study of Human Structure	5

Computer Engineering Track—

		Units
For this track there is a 10 unit minimum for ENGR Fundamentals and a 31 unit minimum for Depth (for track and elective courses)		
EE 108 & EE 180	Digital System Design and Digital Systems Architecture	6-8
Select two of the following:		8
EE 101A	Circuits I	
EE 101B	Circuits II	
EE 102A	Signal Processing and Linear Systems I	
EE 102B	Signal Processing and Linear Systems II	
Satisfy the requirements of one of the following concentrations:		
1) Digital Systems Concentration		
CS 140	Operating Systems and Systems Programming	
or CS 140E or C		
EE 109	Digital Systems Design Lab	
EE 271	Introduction to VLSI Systems	
Plus two of the following (6-8 units):		
CS 140	Operating Systems and Systems Programming (if not counted above)	
or CS 140E or C		
CS 144	Introduction to Computer Networking	
CS 149	Parallel Computing	
CS 190		
CS 240E		
CS 244	Advanced Topics in Networking	
EE 273	Digital Systems Engineering	
EE 282	Computer Systems Architecture	
2) Robotics and Mechatronics Concentration		
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	
CS 223A	Introduction to Robotics	
ME 210	Introduction to Mechatronics	
ENGR 105	Feedback Control Design	
Plus one of the following (3-4 units):		
CS 225A	Experimental Robotics	
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	
ENGR 205	Introduction to Control Design Techniques	
ENGR 207B	Linear Control Systems II	
3) Networking Concentration		
CS 140 & CS 144	Operating Systems and Systems Programming and Introduction to Computer Networking (CS 140E can substitute for CS 140)	
Plus three of the following (9-11 units):		
CS 240	Advanced Topics in Operating Systems	
CS 240E		
CS 241	Embedded Systems Workshop	
CS 244	Advanced Topics in Networking	
CS 244B	Distributed Systems	
CS 244E		
EE 179	Analog and Digital Communication Systems	

Graphics Track—

		Units
CS 148 & CS 248	Introduction to Computer Graphics and Imaging and Interactive Computer Graphics	8
Select one of the following: [5]		3-5
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics (strongly recommended as a preferred choice)	
CME 104	Linear Algebra and Partial Differential Equations for Engineers (Note: students taking CME 104 are also required to take its prerequisite course, CME 102)	
CME 108	Introduction to Scientific Computing	

MATH 52	Integral Calculus of Several Variables	
MATH 113	Linear Algebra and Matrix Theory	
Select two of the following:		6-8
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	
or CS 131	Computer Vision: Foundations and Applications	
CS 233	Geometric and Topological Data Analysis	
CS 268	Geometric Algorithms	
CS 348A	Computer Graphics: Geometric Modeling & Processing	
CS 348B	Computer Graphics: Image Synthesis Techniques	
CS 348C	Computer Graphics: Animation and Simulation	
CS 448	Topics in Computer Graphics	
Track Electives: at least two additional courses from the lists above, the general CS electives list, or the following: [4]		6-8
ARTSTUDI 160	Intro to Digital / Physical Design	
ARTSTUDI 170	PHOTOGRAPHY I: BLACK AND WHITE	
ARTSTUDI 179	Digital Art I	
CME 302	Numerical Linear Algebra	
CME 306	Numerical Solution of Partial Differential Equations	
EE 168	Introduction to Digital Image Processing	
EE 262	Two-Dimensional Imaging	
EE 264	Digital Signal Processing	
EE 278	Introduction to Statistical Signal Processing	
EE 368	Digital Image Processing	
ME 101	Visual Thinking	
PSYCH 30	Introduction to Perception	
PSYCH 221	Image Systems Engineering	

Human-Computer Interaction Track—

		Units
CS 147	Introduction to Human-Computer Interaction Design	4
CS 247	Human-Computer Interaction Design Studio	4
Any three of the following:		
CS 142	Web Applications	
CS 148	Introduction to Computer Graphics and Imaging	
CS 194H	User Interface Design Project	
CS 210A	Software Project Experience with Corporate Partners	
CS 376	Human-Computer Interaction Research	
Any CS 377 'Topics in HCI' of three or more units		
CS 448B	Data Visualization	
ME 216M	Introduction to the Design of Smart Products	
At least two additional courses from above list, the general CS electives list, or the following: [4]		3-6
Any d.school class of 3 or more units		
Any class of 3 or more units at hci.stanford.edu under the 'courses' link		
Communication-		
COMM 121	Behavior and Social Media	
COMM 124	Lies, Trust, and Tech	
or COMM 224	Lies, Trust, and Tech	
COMM 140		
or COMM 240		
COMM 166	Virtual People	
COMM 169		
or COMM 269		
COMM 172	Media Psychology	
or COMM 272	Media Psychology	
COMM 182		
COMM 324	Language and Technology	
Art Studio-		
ARTSTUDI 160	Intro to Digital / Physical Design	
ARTSTUDI 162	Embodied Interfaces	
ARTSTUDI 163	Drawing with Code	
ARTSTUDI 164	DESIGN IN PUBLIC SPACES	
ARTSTUDI 165	Social Media and Performative Practices	
ARTSTUDI 168	Data as Material	
ARTSTUDI 264	Advanced Interaction Design	
ARTSTUDI 266	Sculptural Screens / Malleable Media	
ARTSTUDI 267	Emerging Technology Studio	
Sym Sys-		
SYMSYS 245	Cognition in Interaction Design	
Psychology-		
PSYCH 30	Introduction to Perception	
PSYCH 45	Introduction to Learning and Memory	
PSYCH 70	Self and Society: Introduction to Social Psychology	
PSYCH 75	Introduction to Cultural Psychology	
PSYCH 110	Research Methods and Experimental Design	
PSYCH 131	Language and Thought	
PSYCH 154	Judgment and Decision-Making	
Empirical Methods-		
MS&E 125	Introduction to Applied Statistics	
PSYCH 252	Statistical Methods for Behavioral and Social Sciences	
PSYCH 254	Affective Neuroscience	
PSYCH 110	Research Methods and Experimental Design	
STATS 203	Introduction to Regression Models and Analysis of Variance	
EDUC 191	Introduction to Survey Research	
HUMBIO 82A	Qualitative Research Methodology	
ME Design-		
ME 101	Visual Thinking	
ME 115A	Introduction to Human Values in Design	
ME 203	Design and Manufacturing	
ME 210	Introduction to Mechatronics	
ME 216A	Advanced Product Design: Needfinding	
Learning Design + Tech-		
EDUC 236	Beyond Bits and Atoms: Designing Technological Tools	
EDUC 281	Technology for Learners	
EDUC 239	Educating Young STEM Thinkers	
EDUC 338	Innovations in Education	
EDUC 342	Child Development and New Technologies	
MS&E-		
MS&E 185	Global Work	
MS&E 331		
Computer Music-		
MUSIC 220A	Fundamentals of Computer-Generated Sound	
MUSIC 220B	Compositional Algorithms, Psychoacoustics, and Computational Music	
MUSIC 220C	Research Seminar in Computer-Generated Music	

MUSIC 250A	Physical Interaction Design for Music	
MUSIC 256A	Music, Computing, Design I: Art of Design for Computer Music	
Optional Elective [4]		

Information Track—

		Units
CS 124	From Languages to Information	4
CS 145	Introduction to Databases	4
Two courses, from different areas:		6-9
1) Information-based AI applications		
CS 224N	Natural Language Processing with Deep Learning	
CS 224S	Spoken Language Processing	
CS 229	Machine Learning	
CS 233	Geometric and Topological Data Analysis	
CS 234	Reinforcement Learning	
2) Database and Information Systems		
CS 140	Operating Systems and Systems Programming	
or CS 140E	Operating systems design and implementation	
CS 142	Web Applications	
CS 245	Database Systems Principles	
CS 246	Mining Massive Data Sets	
CS 341	Project in Mining Massive Data Sets	
CS 345	(Offered occasionally)	
CS 346		
CS 347		
3) Information Systems in Biology		
CS 262		
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	
CS 274	Representations and Algorithms for Computational Molecular Biology	
4) Information Systems on the Web		
CS 224W	Analysis of Networks	
CS 276	Information Retrieval and Web Search	
At least three additional courses from the above areas or the general CS electives list. [4]		

Systems Track—

		Units
CS 140	Operating Systems and Systems Programming	4
or CS 140E	Operating systems design and implementation	
Select one of the following:		3-4
CS 143	Compilers	
EE 180	Digital Systems Architecture	
Two additional courses from the list above or the following:		6-8
CS 144	Introduction to Computer Networking	
CS 145	Introduction to Databases	
CS 149	Parallel Computing	
CS 155	Computer and Network Security	
CS 190		
CS 240	Advanced Topics in Operating Systems	
CS 242	Programming Languages	
CS 243	Program Analysis and Optimizations	
CS 244	Advanced Topics in Networking	
CS 245	Database Systems Principles	
EE 271	Introduction to VLSI Systems	
EE 282	Computer Systems Architecture	
Track Electives: at least three additional courses selected from the list above, the general CS electives list, or the following: [4]		9-12
CS 240E		
CS 241	Embedded Systems Workshop	
CS 244E		
CS 316	Advanced Multi-Core Systems	
CS 341	Project in Mining Massive Data Sets	
CS 343	(Not given this year)	
CS 344	Topics in Computer Networks (3 or more units, any suffix)	
CS 345	(Advanced Topics in Database Systems - 3 or more units, any suffix)	
CS 346		
CS 347		
CS 349	Topics in Programming Systems (with permission of undergraduate advisor)	
CS 448	Topics in Computer Graphics	
EE 108	Digital System Design	
EE 382C	Interconnection Networks	
EE 384A	Internet Routing Protocols and Standards	
EE 384B	Multimedia Communication over the Internet	
EE 384C	Wireless Local and Wide Area Networks	
EE 384S	Performance Engineering of Computer Systems & Networks	
EE 384X		

Theory Track—

		Units
CS 154	Introduction to Automata and Complexity Theory	4
Select one of the following:		3
CS 167		
CS 168	The Modern Algorithmic Toolbox	
CS 255	Introduction to Cryptography	
CS 261	Optimization and Algorithmic Paradigms	
CS 264	Beyond Worst-Case Analysis	
CS 265	Randomized Algorithms and Probabilistic Analysis	
CS 268	Geometric Algorithms	
Two additional courses from the list above or the following:		6-8
CS 143	Compilers	
CS 155	Computer and Network Security	
CS 157	Logic and Automated Reasoning	
or PHIL 151	Metalogic	
CS 166	Data Structures	
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	
CS 228	Probabilistic Graphical Models: Principles and Techniques	
CS 233	Geometric and Topological Data Analysis	
CS 242	Programming Languages	
CS 250	Algebraic Error Correcting Codes	
CS 251	Bitcoin and Crypto Currencies	
CS 254	Computational Complexity	
CS 259	(with permission of undergraduate advisor)	
CS 262		
CS 263	Algorithms for Modern Data Models	
CS 266		
CS 267	Graph Algorithms	

CS 269I	Incentives in Computer Science	
CS 352	Pseudo-Randomness	
CS 354	(Not given this year)	
CS 355	(Not given this year)	
CS 357	(Not given this year)	
CS 358	Topics in Programming Language Theory	
CS 359	Topics in the Theory of Computation (with permission of undergraduate advisor)	
CS 364A		
CS 367	(Not given this year)	
CS 369	Topics in Analysis of Algorithms (with permission of undergraduate advisor)	
CS 374		
MS&E 310	Linear Programming	
Track Electives: at least three additional courses from the lists above, the general CS electives list, or the following: [4]		9-12
CS 269G	Almost Linear Time Graph Algorithms	
CME 302	Numerical Linear Algebra	
CME 305	Discrete Mathematics and Algorithms	
PHIL 152	Computability and Logic	

Unspecialized Track—

		Units
CS 154	Introduction to Automata and Complexity Theory	4
Select one of the following:		4
CS 140	Operating Systems and Systems Programming	
or CS 140E	Operating systems design and implementation	
CS 143	Compilers	
One additional course from the list above or the following:		3-4
CS 144	Introduction to Computer Networking	
CS 155	Computer and Network Security	
CS 190		
CS 242	Programming Languages	
CS 244	Advanced Topics in Networking	
EE 180	Digital Systems Architecture	
Select one of the following:		3-4
CS 221	Artificial Intelligence: Principles and Techniques	
CS 223A	Introduction to Robotics	
CS 228	Probabilistic Graphical Models: Principles and Techniques	
CS 229	Machine Learning	
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	
Select one of the following:		3-4
CS 145	Introduction to Databases	
CS 147	Introduction to Human-Computer Interaction Design	
CS 148	Introduction to Computer Graphics and Imaging	
CS 248	Interactive Computer Graphics	
CS 262		
At least two courses from the general CS electives list [4]		

Individually Designed Track—

Students may propose an individually designed track. Proposals should include a minimum of 25 units and seven courses, at least four of which must be CS courses numbered 100 or above. See Handbook for Undergraduate Engineering Programs for further information.

For additional information and sample programs see the Handbook for Undergraduate Engineering Programs (UGHB) (http://ughb.stanford.edu)

1. MATH 19, MATH 20, and MATH 21 OR MATH 41 and MATH 42 OR AP Calculus Credit may be used as long as at least 26 MATH units are taken. AP Calculus Credit must be approved by the School of Engineering.
2. The math electives list consists of: MATH 51, MATH 104, MATH 108, MATH 109, MATH 110, MATH 113; CS 157, CS 205A; PHIL 151; CME 100, CME 102, CME 103 (or EE103), CME 104. Completion of MATH 52 and MATH 53 will together count as one math elective. Restrictions: CS 157 and PHIL 151 may not be used in combination to satisfy the math electives requirement. Students who have taken both MATH 51 and MATH 52 may not count CME 100 as an elective. Courses counted as math electives cannot also count as CS electives, and vice versa.
3. The science elective may be any course of 3 or more units from the School of Engineering Science list (Fig. 4-2 in the UGHB), PSYCH 30, or AP Chemistry Credit. Either of the PHYSICS sequences 61/63 or 21/23 may be substituted for 41/43 as long as at least 11 science units are taken. AP Chemistry Credit and AP Physics Credit must be approved by the School of Engineering.
4. General CS Electives: CS 108,CS 124, CS 131, CS 140 (or CS 140E), CS 142, CS 143 CS 144, CS 145, CS 147, CS 148, CS 149, CS 154, CS 155, CS 157(or PHIL 151), CS 164, CS 166, CS 167, CS 168, CS 190, CS 205A, CS 205B, CS 210A, CS 223A, CS 224N, CS 224S, CS 224U, CS 224W, CS 225A, CS 227B, CS 228, CS 229, CS 229T, CS 231A, CS 231B, CS 231M, CS 231N, CS 232, CS 233, CS 234, CS 238, CS 240, CS 240H, CS 242, CS 243, CS 244, CS 244B, CS 245, CS 246, CS 247, CS 248, CS 249A, CS 251, CS 254, CS 255, CS 261, CS 262, CS 263, CS 264, CS 265, CS 266, CS 267, CS 269I, CS 270, CS 272, CS 273A, CS 273B, CS 274, CS 276, CS 279, CS 348B, CS 348C, CS 352; CME 108; EE 180, EE 282, EE 364A.
5. CS 205A Mathematical Methods for Robotics, Vision, and Graphics is strongly recommended in this list for the Graphics track. Students taking CME 104 Linear Algebra and Partial Differential Equations for Engineers are also required to take its prerequisite, CME 102 Ordinary Differential Equations for Engineers.
6. Independent study projects (CS 191 Senior Project or CS 191W Writing Intensive Senior Project) require faculty sponsorship and must be approved by the adviser, faculty sponsor, and the CS senior project adviser (P. Young). A signed approval form, along with a brief description of the proposed project, should be filed the quarter before work on the project is begun. Further details can be found in the *Handbook for Undergraduate Engineering Programs*.

Honors Program

The Department of Computer Science (CS) offers an honors program for undergraduates whose academic records and personal initiative indicate that they have the necessary skills to undertake high-quality research in computer science. Admission to the program is by application only. To apply for the honors program, students must be majoring in Computer Science, have a grade point average (GPA) of at least 3.6 in courses that count toward the major, and achieve senior standing (135 or more units) by the end of the academic year in which they apply. Coterminal master's students are eligible to apply as long as they have not already received their undergraduate degree. Beyond these requirements, students who apply for the honors program must find a Computer Science faculty member who agrees to serve as the thesis adviser for the project. Thesis advisers must be members of Stanford's Academic Council.

Students who meet the eligibility requirements and wish to be considered for the honors program must submit a written application to the CS undergraduate program office by May 1 of the year preceding the honors work. The application must include a letter describing the research project, a letter of endorsement from the faculty sponsor, and a transcript of courses taken at Stanford. Each year, a faculty review committee selects the successful candidates for honors from the pool of qualified applicants.

In order to receive departmental honors, students admitted to the honors program must, in addition to satisfying the standard requirements for the undergraduate degree, do the following:

1. Complete at least 9 units of CS 191 or CS 191W under the direction of their project sponsor.
2. Attend a weekly honors seminar Winter and Spring quarters.
3. Complete an honors thesis deemed acceptable by the thesis adviser and at least one additional faculty member.
4. Present the thesis at a public colloquium sponsored by the department.
5. Maintain the 3.6 GPA required for admission to the honors program.

Guide to Choosing Introductory Courses

Students arriving at Stanford have widely differing backgrounds and goals, but most find that the ability to use computers effectively is beneficial to their education. The department offers many introductory courses to meet the needs of these students.

For students whose principal interest is an exposure to the fundamental ideas behind computer science and programming, CS 101 or CS 105 are the most appropriate courses. They are intended for students in nontechnical disciplines who expect to make some use of computers, but who do not expect to go on to more advanced courses. CS 101 and CS 105 meet the new Ways of Thinking Ways of Doing breadth requirements in Formal Reasoning and include an introduction to programming and the use of modern Internet-based technologies. Students interested in learning to use the computer should consider CS 1C, Introduction to Computing at Stanford.

Students who intend to pursue a serious course of study in computer science may enter the program at a variety of levels, depending on their background. Students with little prior experience or those who wish to take more time to study the fundamentals of programming should take CS 106A followed by CS 106B. Students in CS 106A need not have prior programming experience. Students with significant prior exposure to programming or those who want an intensive introduction to the field should take CS 106X or may start directly in CS 106B. CS 106A uses Java, JavaScript, or Python as its programming language; CS 106B and X use C++. No prior knowledge of these languages is assumed, and the prior programming experience required for CS 106B or X may be in any language. In all cases, students are encouraged to discuss their background with the instructors responsible for these courses.

After the introductory sequence, Computer Science majors and those who need a significant background in computer science for related majors in engineering should take CS 103, CS 107 and CS 110. CS 103 offers an introduction to the mathematical and theoretical foundations of computer science. CS 107 exposes students to a variety of programming concepts that illustrate critical strategies used in systems development; CS 110 builds on this material, focusing on the development of larger-scale software making use of systems and networking abstractions.

In summary:

For exposure:	
CS 1C	Introduction to Computing at Stanford
For nontechnical use:	
CS 101	Introduction to Computing Principles
or CS 105	Introduction to Computers
For scientific use:	
CS 106A	Programming Methodology
For a technical introduction:	
CS 106A	Programming Methodology
For significant use:	
CS 106A & CS 106B	Programming Methodology and Programming Abstractions
or CS 106X	Programming Abstractions (Accelerated)
CS 103	Mathematical Foundations of Computing
CS 107	Computer Organization and Systems
CS 110	Principles of Computer Systems

Overseas Studies Courses in Computer Science

For course descriptions and additional offerings, see the listings in the *Stanford Bulletin's* ExploreCourses web site (http://explorecourses.stanford.edu) or the Bing Overseas Studies web site (http://bosp.stanford.edu). Students should consult their department or program's student services office for applicability of Overseas Studies courses to a major or minor program.

Joint Major Program: Computer Science and a Humanities Major

The joint major program (JMP), authorized by the Academic Senate for a pilot period of six years beginning in 2014-15, permits students to major in both Computer Science and one of ten Humanities majors. See the "Joint Major Program (http://exploredegrees.stanford.edu/undergraduatedegreesandprograms/#jointmajortext)" section of this bulletin for a description of University requirements for the JMP. See also the Undergraduate Advising and Research JMP web site and its associated FAQs.

Students completing the JMP receive a B.A.S. (Bachelor of Arts and Science).

Because the JMP is new and experimental, changes to procedures may occur; students are advised to check the relevant section of the bulletin periodically.

Mission

The Joint Major provides a unique opportunity to gain mastery in two disciplines: Computer Science and a selected humanities field. Unlike the double major or dual major, the Joint Major emphasizes integration of the two fields through a cohesive, transdisciplinary course of study and integrated capstone experience. The Joint Major not only blends the intellectual traditions of two Stanford departments-it does so in a way that reduces the total unit requirement for each major.

Computer Science Major Requirements in the Joint Major Program

(See the respective humanities department Joint Major Program section of this bulletin for details on humanities major requirements.)

The CS requirements for the Joint Major follow the CS requirements for the CS-BS degree with the following exceptions:

1. Two of the depth electives are waived. The waived depth electives are listed below for each CS track.
2. The Senior Project is fulfilled with a joint capstone project. The student enrolls in CS191 or 191W (3 units) during the senior year. Depending on the X department, enrollment in an additional Humanities capstone course may also be required. But, at a minimum, 3 units of CS191 or 191W must be completed.

3. There is no double-counting of units between majors. If a course is required for both the CS and Humanities majors, the student will work with one of the departments to identify an additional course - one which will benefit the academic plan - to apply to that major's total units requirement.
4. For CS, WIM can be satisfied with CS181W or CS191W.

Depth Electives for CS Tracks for students completing a Joint Major:

Artificial Intelligence Track:

One Track Elective (rather than three).

Biocomputation Track:

One course from Note 3 of the Department Program Sheet, plus one course from Note 4 of the Program Sheet..

Computer Engineering Track:

- EE 108A and 108B
- One of the following: EE 101A, 101B, 102A, 102B
- Satisfy the requirements of one of the following concentrations:

    1. Digital Systems Concentration: CS 140 or 143; EE 109, 271; plus one of CS 140 or 143 (if not counted above), 144, 149, 240E, 244: EE 273, 282
    2. Robotics and Mechatronics Concentration: CS 205A, 223A; ME 210; ENGR 105
    3. Networking Concentration: CS 140, 144; plus two of the following, CS 240, 240E, 244, 244B, 244E, 249A, 249B, EE 179, EE 276

Graphics Track:

No Track Electives required (rather than two)

HCI Track:

No Interdisciplinary HCI Electives required

Information Track:

One Track Elective (rather than three)

Systems Track:

One Track Elective (rather than three)

Theory Track:

One Track Elective (rather than three)

Unspecialized Track:

No Track Electives required (rather than two)

Individually Designed Track:

Proposals should include a minimum of five (rather than seven) courses, at least four of which must be CS courses numbered 100 or above.

Declaring a Joint Major Program

To declare the joint major, students must first declare each major through Axess, and then submit the Declaration or Change of Undergraduate Major, Minor, Honors, or Degree Program. (https://stanford.box.com/change-UG-program) The Major-Minor and Multiple Major Course Approval Form (https://stanford.box.com/MajMin-MultMaj) is required for graduation for students with a joint major.

Dropping a Joint Major Program

To drop the joint major, students must submit the Declaration or Change of Undergraduate Major, Minor, Honors, or Degree Program. (https://stanford.box.com/change-UG-program) . Students may also consult the Student Services Center (http://studentservicescenter.stanford.edu) with questions concerning dropping the joint major.

Transcript and Diploma

Students completing a joint major graduate with a B.A.S. degree. The two majors are identified on one diploma separated by a hyphen. There will be a notation indicating that the student has completed a "Joint Major". The two majors are identified on the transcript with a notation indicating that the student has completed a "Joint Major".

Computer Science (CS) Minor

The following core courses fulfill the minor requirements. Prerequisites include the standard mathematics sequence through MATH 51 (or CME 100).

		Units
Introductory Programming (AP Credit may be used to fulfill this requirement):		
CS 106B	Programming Abstractions	5
or CS 106X	Programming Abstractions (Accelerated)	
Core:		
CS 103	Mathematical Foundations of Computing	5
CS 107	Computer Organization and Systems	5
or CS 107E	Computer Systems from the Ground Up	
CS 109	Introduction to Probability for Computer Scientists	5
Electives (choose two courses from different areas):		
Artificial Intelligence—		
CS 124	From Languages to Information	4
CS 221	Artificial Intelligence: Principles and Techniques	4
CS 229	Machine Learning	3-4
Human-Computer Interaction—		
CS 147	Introduction to Human-Computer Interaction Design	4
Software—		
CS 108	Object-Oriented Systems Design	4
CS 110	Principles of Computer Systems	5
Systems—		
CS 140	Operating Systems and Systems Programming	4
or CS 140E	Operating systems design and implementation	
CS 143	Compilers	4
CS 144	Introduction to Computer Networking	4
CS 145	Introduction to Databases	4
CS 148	Introduction to Computer Graphics and Imaging	4
Theory—		
CS 154	Introduction to Automata and Complexity Theory	4
CS 157	Logic and Automated Reasoning	3
CS 161	Design and Analysis of Algorithms	5

Note: for students with no programming background and who begin with CS 106A, the minor consists of seven courses.

Master of Science in Computer Science

In general, the M.S. degree in Computer Science is intended as a terminal professional degree and does not lead to the Ph.D. degree. Most students planning to obtain the Ph.D. degree should apply directly for admission to the Ph.D. program. Some students, however, may wish to complete the master's program before deciding whether to pursue the Ph.D. To give such students a greater opportunity to become familiar with research, the department has a program leading to a master's degree with distinction in research. This program is described in more detail below.

Admission

Applications to the M.S. program and all supporting documents must be submitted and received online by the published deadline. Information on admission requirements (http://cs.stanford.edu/admissions) is available on the department's web site; see also the department's deadlines page (https://cs.stanford.edu/admissions/deadlines). Exceptions are made for applicants who are already students at Stanford and are applying to the coterminal program (https://cs.stanford.edu/admissions/current-stanford-students/coterminal-program).

University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the "Coterminal Master's Program (http://exploredegrees.stanford.edu/cotermdegrees)" section. University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)" section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken during or after the first quarter of the sophomore year are eligible for consideration for transfer to the graduate career; the timing of the first graduate quarter is not a factor. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate adviser be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

Requirements

A candidate is required to complete a program of 45 units. At least 36 of these must be graded units, passed with a grade point average (GPA) of 3.0 (B) or better. The 45 units may include no more than 10 units of courses from those listed below in Requirement 1. Thus, students needing to take more than two of the courses listed in Requirement 1 actually complete more than 45 units of course work in the program. Only well-prepared students may expect to finish the program in one year; most students complete the program in six quarters. Students hoping to complete the program with 45 units should already have a substantial background in computer science, including course work or experience equivalent to all of Requirement 1 and some prior course work related to their specialization area.

Requirement 1: Foundations—

Students must complete the following courses, or waive out of them by providing evidence to their advisers that similar or more advanced courses have been taken, either at Stanford or another institution (total units used to satisfy foundations requirement may not exceed 10):

Logic, Automata, and Computability	
CS 103	Mathematical Foundations of Computing
Probability	
Select one of the following:	
CS 109	Introduction to Probability for Computer Scientists
STATS 116	Theory of Probability
MS&E 220	Probabilistic Analysis
CME 106	Introduction to Probability and Statistics for Engineers
Algorithmic Analysis	
CS 161	Design and Analysis of Algorithms
Computer Organization and Systems	
CS 107	Computer Organization and Systems
or CS 107E	Computer Systems from the Ground Up
Principles of Computer Systems	
CS 110	Principles of Computer Systems

Requirement 2: Significant Software Implementation—

Students must complete at least one course designated as having a significant software implementation component. The list of such courses includes:

CS 140	Operating Systems and Systems Programming	3-4
or CS 140E	Operating systems design and implementation	
CS 143	Compilers	3-4
CS 144	Introduction to Computer Networking	3-4
CS 145	Introduction to Databases	3-4
CS 148	Introduction to Computer Graphics and Imaging	3-4
CS 190		
CS 210B	Software Project Experience with Corporate Partners	3-4
CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 227B	General Game Playing	3
CS 243	Program Analysis and Optimizations	3-4
CS 248	Interactive Computer Graphics	3-4
CS 341	Project in Mining Massive Data Sets	3
CS 346	(Offered occasionally)	3-5

Requirement 3: Specialization—

Students may choose to satisfy this requirement through one of two options, Single Depth or Dual Depth, outlined following. All courses taken for this requirement must be taken on a letter grade basis for three or more units.

Option 1—Single Depth

- A program of 27 units in a single area of specialization must be completed. A maximum of 9 units of independent study (CS 393, CS 395, CS 399) may be counted toward the specialization.
- Additionally, students must complete three breadth courses from the list of approved breadth courses associated with their chosen specialization. Individual specializations explicitly have different breadth requirements; see the individual specialization sheets on the department's web site (http://cs.stanford.edu/degrees/mscs/programsheets) for details.
- Breadth courses may not be waived, must be taken for at least 3 units each, and must be completed for a letter grade.

Option 2—Dual Depth

- Students select distinct primary and secondary areas.
- A program of 21 units in the primary area of specialization must be completed. A maximum of 9 units of independent study (CS 393, CS 395, CS 399) may be counted toward the primary specialization.
- Students must also complete a program of five courses satisfying the requirements for their secondary area of specialization.
- Breadth courses are not required.

Specialization Areas—

Ten approved specialization areas which may be used to satisfy Requirement 3 are listed following. Students may propose to the M.S.

program committee other coherent programs that meet their goals and satisfy the basic requirements.

Courses marked with an asterisk (*) require consent of the faculty adviser. Courses marked with a double asterisk (**) may be waived by students with equivalent course work and with the approval of their adviser.

1. Artificial Intelligence—

A.

CS 221	Artificial Intelligence: Principles and Techniques **

B. Select at least four of the following:

CS 223A	Introduction to Robotics
CS 224N	Natural Language Processing with Deep Learning
CS 224S	Spoken Language Processing
CS 224U	Natural Language Understanding
CS 224W	Analysis of Networks
CS 228	Probabilistic Graphical Models: Principles and Techniques
CS 229	Machine Learning
CS 231A	Computer Vision: From 3D Reconstruction to Recognition
CS 231N	Convolutional Neural Networks for Visual Recognition
CS 234	Reinforcement Learning
CS 238	Decision Making under Uncertainty

C. A total of at least 27 units from categories A, B, and the following:

CS 205A	Mathematical Methods for Robotics, Vision, and Graphics
CS 225A	Experimental Robotics
CS 227B	General Game Playing
CS 229T	Statistical Learning Theory
CS 231B	
CS 231M	
CS 232	Digital Image Processing
CS 233	Geometric and Topological Data Analysis
CS 239	Advanced Topics in Sequential Decision Making
CS 246	Mining Massive Data Sets
CS 262	
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving
CS 273A	The Human Genome Source Code
CS 273B	Deep Learning in Genomics and Biomedicine
CS 274	Representations and Algorithms for Computational Molecular Biology
CS 275	Translational Bioinformatics
CS 276	Information Retrieval and Web Search
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells
CS 294A	Research Project in Artificial Intelligence *
CS 323	Automated Reasoning: Theory and Applications
CS 325	
CS 326	Topics in Advanced Robotic Manipulation
CS 327A	Advanced Robotic Manipulation (Not given this year)
CS 328	Topics in Computer Vision
CS 329	Topics in Artificial Intelligence
CS 331A	
CS 331B	Representation Learning in Computer Vision
CS 332	Advanced Survey of Reinforcement Learning
CS 333	Safe and Interactive Robotics
CS 334A	Convex Optimization I
or EE 364A	Convex Optimization I
CS 341	Project in Mining Massive Data Sets
CS 345	(Offered occasionally)
CS 362	(Not given this year)
CS 364A	
CS 368	
CS 371	Computational Biology in Four Dimensions
CS 373	Statistical and Machine Learning Methods for Genomics
CS 374	(not given this year)
CS 375	Large-Scale Neural Network Modeling for Neuroscience
CS 377	Topics in Human-Computer Interaction (CS 377 with any suffix) *
CS 379	Interdisciplinary Topics (CS 379 with any suffix) *
CS 393	Computer Laboratory *
CS 395	Independent Database Project *
CS 399	Independent Project *
CS 428	Computation and cognition: the probabilistic approach
APPPHYS 293	Theoretical Neuroscience
BIOE 332	
EE 263	Introduction to Linear Dynamical Systems
EE 278	Introduction to Statistical Signal Processing
EE 364B	Convex Optimization II
EE 376A	Information Theory
EE 377	Information Theory and Statistics
EE 378B	Inference, Estimation, and Information Processing
ENGR 205	Introduction to Control Design Techniques
ENGR 209A	Analysis and Control of Nonlinear Systems
MS&E 226	"Small" Data
MS&E 251	Stochastic Control
MS&E 252	Decision Analysis I: Foundations of Decision Analysis
MS&E 351	Dynamic Programming and Stochastic Control
MS&E 352	Decision Analysis II: Professional Decision Analysis
MS&E 353	Decision Analysis III: Frontiers of Decision Analysis
PSYCH 202	Cognitive Neuroscience
PSYCH 209	Neural Network Models of Cognition: Principles and Applications
STATS 202	Data Mining and Analysis
STATS 315A	Modern Applied Statistics: Learning
STATS 315B	Modern Applied Statistics: Data Mining

- Students with a 27- or 21-unit depth option (Option 1 or 2 above) must take 27 or 21 units respectively subject to satisfying the area (A), (B), and (C) requirements above.
- Students with a secondary area of specialization (per Option 2 above) in Artificial Intelligence must take five total courses satisfying the area (A) and (B) requirements above.
- Those students who have waived out of CS 221 may take an additional course in either area (B) or (C).

Artificial Intelligence Breadth Courses
Students in the single depth specialization must complete three of the following breadth courses and receive a letter grade for each.

CS 140	Operating Systems and Systems Programming	3-4
or CS 140E	Operating systems design and implementation	
CS 143	Compilers	3-4
CS 144	Introduction to Computer Networking	3-4
or EE 284	Introduction to Computer Networks	
CS 145	Introduction to Databases	3-4
CS 147	Introduction to Human-Computer Interaction Design	3-5
CS 148	Introduction to Computer Graphics and Imaging	3-4
CS 149	Parallel Computing	3-4
CS 154	Introduction to Automata and Complexity Theory	3-4
CS 155	Computer and Network Security	3
CS 157	Logic and Automated Reasoning	3
CS 166	Data Structures	3-4
CS 168	The Modern Algorithmic Toolbox	3-4
CS 240	Advanced Topics in Operating Systems	3
CS 240E		
CS 240H		3-4
CS 242	Programming Languages	3
CS 243	Program Analysis and Optimizations	3-4
CS 244	Advanced Topics in Networking	3-4
CS 244B	Distributed Systems	3
CS 244E		
CS 249A		3
CS 255	Introduction to Cryptography	3
CS 261	Optimization and Algorithmic Paradigms	3
CS 264	Beyond Worst-Case Analysis	3
CS 265	Randomized Algorithms and Probabilistic Analysis	3
CS 266		3
CS 267	Graph Algorithms	3
CS 268	Geometric Algorithms	3
CS 269I	Incentives in Computer Science	3
CME 108	Introduction to Scientific Computing	3-4
CME 302	Numerical Linear Algebra	3
EE 180	Digital Systems Architecture	3-4
EE 282	Computer Systems Architecture	3

2. Biocomputation—

A. Select at least four of the following:		
CS 262		
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	
CS 272	Introduction to Biomedical Informatics Research Methodology	
CS 273A	The Human Genome Source Code	
CS 274	Representations and Algorithms for Computational Molecular Biology	
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	
B. A total of at least 27 units from category (A) and the following:		
CS 228	Probabilistic Graphical Models: Principles and Techniques	
CS 229	Machine Learning	
CS 231N	Convolutional Neural Networks for Visual Recognition	
CS 233	Geometric and Topological Data Analysis	
CS 245	Database Systems Principles	
CS 246	Mining Massive Data Sets	
CS 261	Optimization and Algorithmic Paradigms	
CS 264	Beyond Worst-Case Analysis	
CS 265	Randomized Algorithms and Probabilistic Analysis	
CS 268	Geometric Algorithms	
CS 273B	Deep Learning in Genomics and Biomedicine	
CS 275	Translational Bioinformatics	
CS 325		
CS 341	Project in Mining Massive Data Sets	
CS 345	(Offered occasionally)	
CS 346		
CS 362	(Not given this year)	
CS 371	Computational Biology in Four Dimensions	
CS 373	Statistical and Machine Learning Methods for Genomics	
CS 374		
CS 375	Large-Scale Neural Network Modeling for Neuroscience	
CS 393	Computer Laboratory *	
CS 395	Independent Database Project *	
CS 399	Independent Project *	
APPPHYS 293	Theoretical Neuroscience	
BIOC 218		
BIOE 332		
GENE 203		
GENE 211	Genomics	
SBIO 228		

- Students with a 27- or 21-unit depth option (Option 1 or 2 above) must take 27 or 21 units respectively subject to satisfying the area (A) and (B) requirements above.
- Students with a secondary area of specialization (per Option 2 above) in Biocomputation must take five total courses, three courses of which must come from area (A) and the remaining two courses may come from either area (A) or (B).

Biocomputation Breadth Courses
Students in the single depth specialization must complete three of the following breadth courses and receive a letter grade for each.

CS 124	From Languages to Information	3-4
CS 140	Operating Systems and Systems Programming	3-4
or CS 140E	Operating systems design and implementation	
CS 143	Compilers	3-4
CS 144	Introduction to Computer Networking	3-4
or EE 284	Introduction to Computer Networks	
CS 145	Introduction to Databases	3-4
CS 147	Introduction to Human-Computer Interaction Design	3-5
CS 148	Introduction to Computer Graphics and Imaging	3-4
CS 149	Parallel Computing	3-4
CS 154	Introduction to Automata and Complexity Theory	3-4
CS 155	Computer and Network Security	3
CS 157	Logic and Automated Reasoning	3
CS 166	Data Structures	3-4
CS 168	The Modern Algorithmic Toolbox	3-4
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	3

CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 223A	Introduction to Robotics	3
CS 224N	Natural Language Processing with Deep Learning	3-4
CS 224S	Spoken Language Processing	2-4
CS 224U	Natural Language Understanding	3-4
CS 224W	Analysis of Networks	3
CS 227B	General Game Playing	3
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	3
or CS 231B		
CS 234	Reinforcement Learning	3
CS 240	Advanced Topics in Operating Systems	3
CS 240E		
CS 240H		3-4
CS 242	Programming Languages	3
CS 243	Program Analysis and Optimizations	3-4
CS 244	Advanced Topics in Networking	3-4
CS 244B	Distributed Systems	3
CS 244E		
CS 249A		3
CS 255	Introduction to Cryptography	3
CS 269I	Incentives in Computer Science	3
CS 276	Information Retrieval and Web Search	3
CME 108	Introduction to Scientific Computing	3-4
CME 302	Numerical Linear Algebra	3
EE 180	Digital Systems Architecture	3-4
EE 282	Computer Systems Architecture	3

3. Computer and Network Security—

A.		
CS 140	Operating Systems and Systems Programming **	
or CS 140E	Operating systems design and implementation	
CS 144	Introduction to Computer Networking **	
CS 155	Computer and Network Security	
CS 244	Advanced Topics in Networking	
CS 255	Introduction to Cryptography	
B. Select at least three of the following:		
CS 142	Web Applications	
CS 190		
CS 240	Advanced Topics in Operating Systems	
CS 244B	Distributed Systems	
CS 261	Optimization and Algorithmic Paradigms	
CS 265	Randomized Algorithms and Probabilistic Analysis	
CS 340	Topics in Computer Systems	
CS 344	Topics in Computer Networks (CS 344 with any suffix)	
CS 355	(Not given this year)	
C. A total of at least 27 units from categories (A), (B), and the following:		
CS 240E		
CS 244E		
CS 245	Database Systems Principles	
CS 251	Bitcoin and Crypto Currencies	
CS 264	Beyond Worst-Case Analysis	
CS 294S	Research Project in Software Systems and Security (Not given this year) *	
CS 341	Project in Mining Massive Data Sets	
CS 345	(Offered occasionally)	
CS 347		
CS 393	Computer Laboratory *	
CS 395	Independent Database Project *	
CS 399	Independent Project *	
EE 384A	Internet Routing Protocols and Standards	
EE 384C	Wireless Local and Wide Area Networks	
EE 384S	Performance Engineering of Computer Systems & Networks	

- Students with a 27- or 21-unit depth option (Option 1 or 2 above) must take 27 or 21 units respectively subject to satisfying the area (A), (B), and (C) requirements above.
- Students with a secondary area of specialization (per Option 2 above) in Computer and Network Security must take five courses; those five courses must satisfy the area (A) requirement and additional courses from area (B) should be taken if any area (A) requirements are waived.

Computer and Network Security Breadth Courses

Students in the single depth specialization must complete three of the following breadth courses and receive a letter grade for each.

CS 124	From Languages to Information	3-4
CS 143	Compilers	3-4
CS 147	Introduction to Human-Computer Interaction Design	3-5
CS 148	Introduction to Computer Graphics and Imaging	3-4
CS 149	Parallel Computing	3-4
CS 154	Introduction to Automata and Complexity Theory	3-4
CS 157	Logic and Automated Reasoning	3
CS 166	Data Structures	3-4
CS 168	The Modern Algorithmic Toolbox	3-4
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	3
CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 223A	Introduction to Robotics	3
CS 224N	Natural Language Processing with Deep Learning	3-4
CS 224S	Spoken Language Processing	2-4
CS 224U	Natural Language Understanding	3-4
CS 224W	Analysis of Networks	3
CS 227B	General Game Playing	3
CS 228	Probabilistic Graphical Models: Principles and Techniques	3-4
CS 229	Machine Learning	3-4
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	3
or CS 231B		
CS 233	Geometric and Topological Data Analysis	3
CS 234	Reinforcement Learning	3
CS 242	Programming Languages	3
CS 243	Program Analysis and Optimizations	3-4
CS 246	Mining Massive Data Sets	3-4
CS 249A		3
CS 262		3
CS 267	Graph Algorithms	3
CS 268	Geometric Algorithms	3
CS 269I	Incentives in Computer Science	3
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	3
CS 273A	The Human Genome Source Code	3

CS 274	Representations and Algorithms for Computational Molecular Biology	3-4
CS 276	Information Retrieval and Web Search	3
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3
CME 108	Introduction to Scientific Computing	3-4
CME 302	Numerical Linear Algebra	3
EE 180	Digital Systems Architecture	3-4
EE 282	Computer Systems Architecture	3

4. Human-Computer Interaction—

A.	
CS 147	Introduction to Human-Computer Interaction Design **
CS 247	Human-Computer Interaction Design Studio **
B. Select any three of the following:	
CS 142	Web Applications
CS 148	Introduction to Computer Graphics and Imaging
CS 194H	User Interface Design Project
CS 210A	Software Project Experience with Corporate Partners
CS 248	Interactive Computer Graphics
CS 376	Human-Computer Interaction Research
CS 377	Topics in Human-Computer Interaction (CS 377 with any suffix)
CS 448B	Data Visualization
ME 216M	Introduction to the Design of Smart Products
C. A total of at least 27 units from categories (A), (B), and the following:	
a. Broader CS	
CS 221	Artificial Intelligence: Principles and Techniques
CS 224N	Natural Language Processing with Deep Learning
CS 224U	Natural Language Understanding
CS 224W	Analysis of Networks
CS 229	Machine Learning
CS 231A	Computer Vision: From 3D Reconstruction to Recognition
CS 231B	
CS 242	Programming Languages
CS 246	Mining Massive Data Sets
CS 341	Project in Mining Massive Data Sets
CS 393	Computer Laboratory *
CS 395	Independent Database Project *
CS 399	Independent Project *
b. Art Studio	
ARTSTUDI 160	Intro to Digital / Physical Design
ARTSTUDI 162	Embodied Interfaces
ARTSTUDI 163	Drawing with Code
ARTSTUDI 164	DESIGN IN PUBLIC SPACES
ARTSTUDI 165	Social Media and Performative Practices
ARTSTUDI 168	Data as Material
ARTSTUDI 264	Advanced Interaction Design
ARTSTUDI 266	Sculptural Screens / Malleable Media
ARTSTUDI 267	Emerging Technology Studio
c. Communication	
COMM 224	Lies, Trust, and Tech
COMM 240	
COMM 266	Virtual People
COMM 269	
COMM 272	Media Psychology
Comm 282	
COMM 324	Language and Technology
d. Empirical Methods	
COMM 314	Ethnographic Methods
EDUC 200B	Introduction to Qualitative Research Methods
MS&E 125	Introduction to Applied Statistics
PSYCH 252	Statistical Methods for Behavioral and Social Sciences
PSYCH 254	Affective Neuroscience
STATS 203	Introduction to Regression Models and Analysis of Variance
e. Learning Design & Tech	
EDUC 236	Beyond Bits and Atoms: Designing Technological Tools
EDUC 239	Educating Young STEM Thinkers
EDUC 281	Technology for Learners
EDUC 338	Innovations in Education
EDUC 342	Child Development and New Technologies
f. Management Science & Engr	
MS&E 185	Global Work
MS&E 331	
MS&E 334	Topics in Social Data
g. Mechanical Engr	
ME 203	Design and Manufacturing
ME 210	Introduction to Mechatronics
ME 216A	Advanced Product Design: Needfinding
h. Music	
MUSIC 220A	Fundamentals of Computer-Generated Sound
MUSIC 220B	Compositional Algorithms, Psychoacoustics, and Computational Music
MUSIC 220C	Research Seminar in Computer-Generated Music
MUSIC 250A	Physical Interaction Design for Music
MUSIC 256A	Music, Computing, Design I: Art of Design for Computer Music
i. Psych	
PSYCH 204	Computation and cognition: the probabilistic approach
PSYCH 209	Neural Network Models of Cognition: Principles and Applications
j. Sym Sys	
SYMSYS 245	Cognition in Interaction Design
Additional courses [1]	

[1] Any d.school course (http://dschool.stanford.edu) or any HCI course (http://hci.stanford.edu/courses); such courses must be numbered 100 or above and be taken for at least 3 units to count for this requirement

- Students with a 27- or 21-unit depth option (Option 1 or 2 above) must take 27 or 21 units respectively subject to satisfying the area (A) through (C) requirements above.
- Students with a secondary area of specialization (per Option 2 above) in Human-Computer Interaction must take five courses satisfying the areas (A) through (C).

Human-Computer Interaction Breadth Courses

Students in the single depth specialization must complete three of the following breadth courses and receive a letter grade for each.

CS 124	From Languages to Information	3-4
CS 140	Operating Systems and Systems Programming	3-4
or CS 140E	Operating systems design and implementation	
CS 143	Compilers	3-4
CS 144	Introduction to Computer Networking	3-4
or EE 284	Introduction to Computer Networks	
CS 145	Introduction to Databases	3-4
CS 149	Parallel Computing	3-4
CS 154	Introduction to Automata and Complexity Theory	3-4
CS 155	Computer and Network Security	3
CS 157	Logic and Automated Reasoning	3
CS 166	Data Structures	3-4
CS 168	The Modern Algorithmic Toolbox	3-4
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	3
CS 223A	Introduction to Robotics	3
CS 224S	Spoken Language Processing	2-4
CS 227B	General Game Playing	3
CS 228	Probabilistic Graphical Models: Principles and Techniques	3-4
CS 233	Geometric and Topological Data Analysis	3
CS 234	Reinforcement Learning	3
CS 240	Advanced Topics in Operating Systems	3
CS 240E		
CS 240H		3-4
CS 243	Program Analysis and Optimizations	3-4
CS 244	Advanced Topics in Networking	3-4
CS 244B	Distributed Systems	3
CS 244E		
CS 249A		3
CS 255	Introduction to Cryptography	3
CS 261	Optimization and Algorithmic Paradigms	3
CS 262		3
CS 264	Beyond Worst-Case Analysis	3
CS 265	Randomized Algorithms and Probabilistic Analysis	3
CS 266		3
CS 267	Graph Algorithms	3
CS 268	Geometric Algorithms	3
CS 269I	Incentives in Computer Science	3
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	3
CS 273A	The Human Genome Source Code	3
CS 274	Representations and Algorithms for Computational Molecular Biology	3-4
CS 276	Information Retrieval and Web Search	3
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3
CME 108	Introduction to Scientific Computing	3-4
CME 302	Numerical Linear Algebra	3
EE 180	Digital Systems Architecture	3-4
EE 282	Computer Systems Architecture	3

5. Information Management and Analytics—

A.		
CS 145	Introduction to Databases **	3-4
B. Select at least four of the following:		
CS 224N	Natural Language Processing with Deep Learning	
CS 224W	Analysis of Networks	
CS 229	Machine Learning	
CS 245	Database Systems Principles	
CS 246	Mining Massive Data Sets	
CS 276	Information Retrieval and Web Search	
CS 345	(Offered occasionally)	
CS 346	(no longer offered)	
CS 347		
C. A total of at least 27 units from categories (A), (B) and the following:		
CS 144	Introduction to Computer Networking	
CS 190		
CS 224S	Spoken Language Processing	
CS 224U	Natural Language Understanding	
CS 228	Probabilistic Graphical Models: Principles and Techniques	
CS 229T	Statistical Learning Theory	
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	
CS 231N	Convolutional Neural Networks for Visual Recognition	
CS 233	Geometric and Topological Data Analysis	
CS 234	Reinforcement Learning	
CS 240	Advanced Topics in Operating Systems	
CS 242	Programming Languages	
CS 243	Program Analysis and Optimizations	
CS 244	Advanced Topics in Networking	
CS 244B	Distributed Systems	
CS 249A		
CS 251	Bitcoin and Crypto Currencies	
CS 255	Introduction to Cryptography	
CS 262		
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	
CS 272	Introduction to Biomedical Informatics Research Methodology	
CS 273A	The Human Genome Source Code	
CS 274	Representations and Algorithms for Computational Molecular Biology	
CS 275	Translational Bioinformatics	
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	
CS 316	Advanced Multi-Core Systems	
CS 325		
CS 341	Project in Mining Massive Data Sets	
CS 344	Topics in Computer Networks (CS 344 with any suffix)	
CS 362	(Not given this year)	
CS 374		
CS 393	Computer Laboratory *	
CS 395	Independent Database Project *	
CS 399	Independent Project *	
MS&E 226	"Small" Data	
STATS 315A	Modern Applied Statistics: Learning	
STATS 315B	Modern Applied Statistics: Data Mining	

- Students with a 27- or 21-unit depth option (Option 1 or 2 above) must take 27 or 21 units respectively subject to satisfying the area (A), (B), and (C) requirements above.

- Students with a secondary area of specialization (per Option 2 above) in Information Management and Analytics must take five courses satisfying the area (A) and (B) requirements above. Note that if CS145 was waived in area (A), students should take an additional course from either area (B) or (C) in its place.

Information Management and Analytics Breadth Courses
Students in the single depth specialization must complete three of the following breadth courses and receive a letter grade for each.

CS 124	From Languages to Information	3-4
CS 140	Operating Systems and Systems Programming	3-4
or CS 140E	Operating systems design and implementation	
CS 147	Introduction to Human-Computer Interaction Design	3-5
CS 148	Introduction to Computer Graphics and Imaging	3-4
CS 149	Parallel Computing	3-4
CS 154	Introduction to Automata and Complexity Theory	3-4
CS 155	Computer and Network Security	3
CS 157	Logic and Automated Reasoning	3
CS 166	Data Structures	3-4
CS 168	The Modern Algorithmic Toolbox	3-4
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	3
CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 223A	Introduction to Robotics	3
CS 227B	General Game Playing	3
CS 240E		
CS 244E		
CS 261	Optimization and Algorithmic Paradigms	3
CS 264	Beyond Worst-Case Analysis	3
CS 265	Randomized Algorithms and Probabilistic Analysis	3
CS 266		3
CS 267	Graph Algorithms	3
CS 268	Geometric Algorithms	3
CS 269I	Incentives in Computer Science	3
CME 108	Introduction to Scientific Computing	3-4
CME 302	Numerical Linear Algebra	3
EE 180	Digital Systems Architecture	3-4
EE 282	Computer Systems Architecture	3

6. Mobile and Internet Computing—

A. Select two of the following:		
CS 140	Operating Systems and Systems Programming **	
or CS 140E	Operating systems design and implementation	
CS 144	Introduction to Computer Networking	
CS 244	Advanced Topics in Networking	
B. Select one of the following:		
CS 142	Web Applications	
CS 147	Introduction to Human-Computer Interaction Design	
CS 247	Human-Computer Interaction Design Studio	
C. Select one of the following:		
CS 155	Computer and Network Security	
CS 255	Introduction to Cryptography	
D.		
CS 294S	Research Project in Software Systems and Security	
E. A total of 27 units from categories (A), (B), (C), (D) and the following:		
CS 190		
CS 224W	Analysis of Networks	
CS 241	Embedded Systems Workshop	
CS 244E		
CS 246	Mining Massive Data Sets	
CS 251	Bitcoin and Crypto Currencies	
CS 344	Topics in Computer Networks (CS 344 with any suffix)	
CS 364A		
CS 376	Human-Computer Interaction Research	
CS 393	Computer Laboratory *	
CS 395	Independent Database Project *	
CS 399	Independent Project *	
EE 359	Wireless Communications	
EE 384A	Internet Routing Protocols and Standards	
EE 384B	Multimedia Communication over the Internet (not given this year)	
EE 384C	Wireless Local and Wide Area Networks	
EE 384E	Networked Wireless Systems	
EE 384S	Performance Engineering of Computer Systems & Networks	
COMM 268		
PSYCH 252	Statistical Methods for Behavioral and Social Sciences	

- Students with a 27- or 21-unit depth option (Option 1 or 2 above) must take 27 or 21 units respectively subject to satisfying the area (A) through (E) requirements above.
- Students with a secondary area of specialization (per Option 2 above) in Mobile and Internet Computing must take five courses satisfying the area (A) through (D) requirements above.

Mobile and Internet Computing Breadth Courses
Students in the single depth specialization must complete three of the following breadth courses and receive a letter grade for each.

CS 124	From Languages to Information	3-4
CS 143	Compilers	3-4
CS 145	Introduction to Databases	3-4
CS 148	Introduction to Computer Graphics and Imaging	3-4
CS 149	Parallel Computing	3-4
CS 154	Introduction to Automata and Complexity Theory	3-4
CS 157	Logic and Automated Reasoning	3
CS 166	Data Structures	3-4
CS 168	The Modern Algorithmic Toolbox	3-4
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	3
CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 223A	Introduction to Robotics	3
CS 224N	Natural Language Processing with Deep Learning	3-4
CS 224S	Spoken Language Processing	2-4
CS 224U	Natural Language Understanding	3-4
CS 227B	General Game Playing	3
CS 228	Probabilistic Graphical Models: Principles and Techniques	3-4
CS 229	Machine Learning	3-4
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	3
or CS 231B		
CS 233	Geometric and Topological Data Analysis	3

CS 234	Reinforcement Learning	3
CS 240	Advanced Topics in Operating Systems	3
CS 240E	(no longer offered)	
CS 240H		3-4
CS 242	Programming Languages	3
CS 243	Program Analysis and Optimizations	3-4
CS 244B	Distributed Systems	3
CS 249A		3
CS 261	Optimization and Algorithmic Paradigms	3
CS 262		3
CS 264	Beyond Worst-Case Analysis	3
CS 265	Randomized Algorithms and Probabilistic Analysis	3
CS 266		3
CS 267	Graph Algorithms	3
CS 268	Geometric Algorithms	3
CS 269I	Incentives in Computer Science	3
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	3
CS 273A	The Human Genome Source Code	3
CS 274	Representations and Algorithms for Computational Molecular Biology	3-4
CS 276	Information Retrieval and Web Search	3
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3
CME 108	Introduction to Scientific Computing	3-4
CME 302	Numerical Linear Algebra	3
EE 180	Digital Systems Architecture	3-4
EE 282	Computer Systems Architecture	3

7. Real-World Computing—

A. Select at least three of the following:		
CS 148	Introduction to Computer Graphics and Imaging	
CS 223A	Introduction to Robotics	
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	
CS 248	Interactive Computer Graphics	
B. Select at least three of the following:		
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	
CS 233	Geometric and Topological Data Analysis	
CS 249A		
CS 262		
CS 268	Geometric Algorithms	
CS 348A	Computer Graphics: Geometric Modeling & Processing	
CS 348B	Computer Graphics: Image Synthesis Techniques	
CS 348C	Computer Graphics: Animation and Simulation	
CS 374		
CME 302	Numerical Linear Algebra	
CME 306	Numerical Solution of Partial Differential Equations	
C. A total of at least 27 units from categories (A), (B), and the following:		
CS 225A	Experimental Robotics	
CS 228	Probabilistic Graphical Models: Principles and Techniques	
CS 229	Machine Learning	
CS 231B		
CS 231M		
CS 232	Digital Image Processing	
or EE 368	Digital Image Processing	
CS 247	Human-Computer Interaction Design Studio	
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	
CS 272	Introduction to Biomedical Informatics Research Methodology	
CS 273A	The Human Genome Source Code	
CS 274	Representations and Algorithms for Computational Molecular Biology	
CS 294A	Research Project in Artificial Intelligence *	
CS 326	Topics in Advanced Robotic Manipulation	
CS 327A	Advanced Robotic Manipulation (Not given this year)	
CS 328	Topics in Computer Vision	
CS 331A		
CS 331B	Representation Learning in Computer Vision	
CS 333	Safe and Interactive Robotics	
CS 393	Computer Laboratory *	
CS 395	Independent Database Project *	
CS 399	Independent Project *	
CS 448	Topics in Computer Graphics (CS 448 with any suffix)	
EE 267	Virtual Reality	

- Students with a 27- or 21-unit depth option (Option 1 or 2 above) must take 27 or 21 units respectively subject to satisfying the area (A), (B), and (C) requirements above.
- Students with a secondary area of specialization (per Option 2 above) in Real-World Computing must take five total courses satisfying area (A) and two of the three courses in the area (B) requirements above (i.e., three courses in area (a) and two courses in area (B).

Real-World Computing Breadth Courses

Students in the single depth specialization must complete three of the following breadth courses and receive a letter grade for each.

CS 124	From Languages to Information	3-4
CS 140 or CS 140E	Operating Systems and Systems Programming	3-4
CS 143	Compilers	3-4
CS 144	Introduction to Computer Networking	3-4
or EE 284	Introduction to Computer Networks	
CS 145	Introduction to Databases	3-4
CS 147	Introduction to Human-Computer Interaction Design	3-5
CS 149	Parallel Computing	3-4
CS 154	Introduction to Automata and Complexity Theory	3-4
CS 155	Computer and Network Security	3
CS 157	Logic and Automated Reasoning	3
CS 166	Data Structures	3-4
CS 168	The Modern Algorithmic Toolbox	3-4
CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 224N	Natural Language Processing with Deep Learning	3-4
CS 224S	Spoken Language Processing	2-4
CS 224U	Natural Language Understanding	3-4
CS 224W	Analysis of Networks	3
CS 227B	General Game Playing	3
CS 234	Reinforcement Learning	3
CS 240	Advanced Topics in Operating Systems	3

CS 240E	(no longer offered)	
CS 240H		3-4
CS 242	Programming Languages	3
CS 243	Program Analysis and Optimizations	3-4
CS 244	Advanced Topics in Networking	3-4
CS 244B	Distributed Systems	3
CS 244E		
CS 246	Mining Massive Data Sets	3
CS 255	Introduction to Cryptography	3
CS 261	Optimization and Algorithmic Paradigms	3
CS 264	Beyond Worst-Case Analysis	3
CS 265	Randomized Algorithms and Probabilistic Analysis	3
CS 266		3
CS 267	Graph Algorithms	3
CS 269I	Incentives in Computer Science	3
CS 276	Information Retrieval and Web Search	3
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3
CME 108	Introduction to Scientific Computing	3-4
EE 180	Digital Systems Architecture	3-4
EE 282	Computer Systems Architecture	3

8. Software Theory—

A.	
CS 243	Program Analysis and Optimizations
B. Select at least one of the following:	
CS 244	Advanced Topics in Networking
CS 245	Database Systems Principles
CS 341	Project in Mining Massive Data Sets
CS 343	(Offered occasionally)
CS 345	(Offered occasionally)
C. Select at least two courses from the following:	
CS 242	Programming Languages
CS 255	Introduction to Cryptography
CS 261	Optimization and Algorithmic Paradigms
CS 263	Algorithms for Modern Data Models
CS 264	Beyond Worst-Case Analysis
CS 265	Randomized Algorithms and Probabilistic Analysis
CS 266	
CS 267	Graph Algorithms
CS 268	Geometric Algorithms
CS 355	(Not given this year)
CS 367	(Not given this year)
D. A total of at least 27 units from (A), (B), (C), or the following:	
CS 250	Algebraic Error Correcting Codes
CS 251	Bitcoin and Crypto Currencies
CS 294S	Research Project in Software Systems and Security (Not given this year) *
CS 346	
CS 362	(Not given this year)
CS 393	Computer Laboratory *
CS 395	Independent Database Project *
CS 399	Independent Project *

- Students with a 27- or 21-unit depth option (Option 1 or 2 above) must take 27 or 21 units respectively subject to satisfying the area (A) through (D) requirements above.
- Students with a secondary area of specialization (per Option 2 above) in Software Theory need to take 5 total courses satisfying the area (A) through (D) requirements above.

Software Theory Breadth Courses

Students in the single depth specialization must complete three of the following breadth courses and receive a letter grade for each.

CS 124	From Languages to Information	3-4
CS 140	Operating Systems and Systems Programming	3-4
or CS 140E	Operating systems design and implementation	
CS 147	Introduction to Human-Computer Interaction Design	3-5
CS 148	Introduction to Computer Graphics and Imaging	3-4
CS 149	Parallel Computing	3-4
CS 154	Introduction to Automata and Complexity Theory	3-4
CS 155	Computer and Network Security	3
CS 157	Logic and Automated Reasoning	3
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	3
CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 223A	Introduction to Robotics	3
CS 224N	Natural Language Processing with Deep Learning	3-4
CS 224S	Spoken Language Processing	2-4
CS 224U	Natural Language Understanding	3-4
CS 224W	Analysis of Networks	3
CS 227B	General Game Playing	3
CS 228	Probabilistic Graphical Models: Principles and Techniques	3-4
CS 229	Machine Learning	3-4
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	3
or CS 231B		
CS 233	Geometric and Topological Data Analysis	3
CS 234	Reinforcement Learning	3
CS 240	Advanced Topics in Operating Systems	3
CS 240E	(no longer offered)	
CS 240H		3-4
CS 244B	Distributed Systems	3
CS 244E		
CS 246	Mining Massive Data Sets	3-4
CS 249A		3
CS 262		3
CS 269I	Incentives in Computer Science	3
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	3
CS 273A	The Human Genome Source Code	3
CS 274	Representations and Algorithms for Computational Molecular Biology	3-4
CS 276	Information Retrieval and Web Search	3
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3
CME 108	Introduction to Scientific Computing	3-4
CME 302	Numerical Linear Algebra	3
EE 180	Digital Systems Architecture	3-4
EE 282	Computer Systems Architecture	3

9. Systems—

A.	
CS 140	Operating Systems and Systems Programming **

or CS 140E	Operating systems design and implementation
CS 144	Introduction to Computer Networking **
CS 240	Advanced Topics in Operating Systems

B. Select at least four of the following:

CS 190	
CS 242	Programming Languages
CS 243	Program Analysis and Optimizations
CS 244	Advanced Topics in Networking
CS 245	Database Systems Principles
CS 248	Interactive Computer Graphics
CS 348B	Computer Graphics: Image Synthesis Techniques
EE 271	Introduction to VLSI Systems
EE 282	Computer Systems Architecture

C. A total of at least 27 units from categories (A), (B), and the following:

CS 240E	(no longer offered)
CS 240H	
CS 241	Embedded Systems Workshop
CS 244B	Distributed Systems
CS 244E	
CS 246	Mining Massive Data Sets
CS 249A	
CS 251	Bitcoin and Crypto Currencies
CS 255	Introduction to Cryptography
CS 262	
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving
CS 272	Introduction to Biomedical Informatics Research Methodology
CS 276	Information Retrieval and Web Search
CS 294S	Research Project in Software Systems and Security (Not given this year) *
CS 315B	Parallel Computing Research Project
CS 316	Advanced Multi-Core Systems
CS 340	Topics in Computer Systems
CS 341	Project in Mining Massive Data Sets
CS 343	(Not given this year)
CS 344	Topics in Computer Networks (CS 344 with any suffix)
CS 345	(Offered occasionally)
CS 346	
CS 347	
CS 348A	Computer Graphics: Geometric Modeling & Processing
CS 348C	Computer Graphics: Animation and Simulation
CS 349	Topics in Programming Systems (CS 349 with any suffix)
CS 374	
CS 393	Computer Laboratory *
CS 395	Independent Database Project *
CS 399	Independent Project *
CS 448	Topics in Computer Graphics (CS 448 with any suffix)
EE 267	Virtual Reality
EE 273	Digital Systems Engineering
EE 382C	Interconnection Networks
EE 384A	Internet Routing Protocols and Standards
EE 384B	Multimedia Communication over the Internet (not given this year)
EE 384C	Wireless Local and Wide Area Networks
EE 384S	Performance Engineering of Computer Systems & Networks

- Students with a 27-unit depth option (Option 1 above) must take 27 units subject to satisfying the area (A), (B), and (C) requirements above.
- Students with a 21-unit depth option (Option 2 above) must take that many units subject to satisfying the area (A) and (B) requirements above, and additional courses may be taken from area (C) if any courses in the area (A) requirement are waived.
- Students with a secondary area of specialization (per Option 2 above) in Systems need to take five courses; those courses must satisfy the area (A) requirement and additional courses may be taken from area (B).

Systems Breadth Courses

Students in the single depth specialization must complete three of the following breadth courses and receive a letter grade for each.

CS 124	From Languages to Information	3-4
CS 147	Introduction to Human-Computer Interaction Design	3-5
CS 154	Introduction to Automata and Complexity Theory	3-4
CS 155	Computer and Network Security	3
CS 157	Logic and Automated Reasoning	3
CS 166	Data Structures	3-4
CS 168	The Modern Algorithmic Toolbox	3-4
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	3
CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 223A	Introduction to Robotics	3
CS 224N	Natural Language Processing with Deep Learning	3-4
CS 224S	Spoken Language Processing	2-4
CS 224U	Natural Language Understanding	3-4
CS 224W	Analysis of Networks	3
CS 227B	General Game Playing	3
CS 228	Probabilistic Graphical Models: Principles and Techniques	3-4
CS 229	Machine Learning	3-4
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	3
or CS 231B		
CS 233	Geometric and Topological Data Analysis	3
CS 234	Reinforcement Learning	3
CS 261	Optimization and Algorithmic Paradigms	3
CS 264	Beyond Worst-Case Analysis	3
CS 265	Randomized Algorithms and Probabilistic Analysis	3
CS 266		3
CS 267	Graph Algorithms	3
CS 268	Geometric Algorithms	3
CS 269I	Incentives in Computer Science	3
CS 273A	The Human Genome Source Code	3
CS 274	Representations and Algorithms for Computational Molecular Biology	3-4
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3
CME 108	Introduction to Scientific Computing	3-4

CME 302	Numerical Linear Algebra	3

10. Theoretical Computer Science—

A.	
CS 154	Introduction to Automata and Complexity Theory **
CS 261	Optimization and Algorithmic Paradigms
B. A total of at least 27 units from category (A) and the following:	
CS 166	Data Structures
CS 168	The Modern Algorithmic Toolbox
CS 228	Probabilistic Graphical Models: Principles and Techniques
CS 233	Geometric and Topological Data Analysis
CS 246	Mining Massive Data Sets
CS 250	Algebraic Error Correcting Codes
CS 251	Bitcoin and Crypto Currencies
CS 254	Computational Complexity
CS 255	Introduction to Cryptography
CS 262	
CS 263	Algorithms for Modern Data Models
CS 264	Beyond Worst-Case Analysis
CS 265	Randomized Algorithms and Probabilistic Analysis
CS 266	
CS 267	Graph Algorithms
CS 268	Geometric Algorithms
CS 269G	Almost Linear Time Graph Algorithms
CS 269I	Incentives in Computer Science
CS 334A	Convex Optimization I
or EE 364A	Convex Optimization I
CS 341	Project in Mining Massive Data Sets
CS 345	(Offered occasionally)
CS 352	Pseudo-Randomness
CS 354	(Not given this year)
CS 355	(Not given this year)
CS 357	(Not given this year)
CS 358	Topics in Programming Language Theory
CS 359	Topics in the Theory of Computation *
CS 362	(Not given this year)
CS 364A	
CS 366	(Not given this year)
CS 367	(Not given this year)
CS 368	
CS 369	Topics in Analysis of Algorithms *
CS 374	(not given this year)
CS 393	Computer Laboratory *
CS 395	Independent Database Project *
CS 399	Independent Project *
CS 468	Topics in Geometric Algorithms: Machine Learning for 3D Data *
MS&E 310	Linear Programming
MS&E 319	Approximation Algorithms

- Multiple CS 359, CS 369, and/or CS 468 courses may be taken as long as they are each on different topics, denoted by different letter suffixes for the courses.
- Students with a 27- or 21-unit depth option (Option 1 or 2 above) must take 27 or 21 units respectively subject to satisfying the area (A) and (B) requirements above.
- Students with a secondary area of specialization (per Option 2 above) in Theoretical Computer Science need to take 5 total courses satisfying the area (A) and (B) requirements above.

Theoretical Computer Science Breadth Courses

Students in the single depth specialization must complete three of the following breadth courses and receive a letter grade for each.

CS 124	From Languages to Information	3-4
CS 140	Operating Systems and Systems Programming	3-4
or CS 140E	Operating systems design and implementation	
CS 143	Compilers	3-4
CS 144	Introduction to Computer Networking	3-4
or EE 284	Introduction to Computer Networks	
CS 145	Introduction to Databases	3-4
CS 147	Introduction to Human-Computer Interaction Design	3-5
CS 148	Introduction to Computer Graphics and Imaging	3-4
CS 149	Parallel Computing	3-4
CS 155	Computer and Network Security	3
CS 157	Logic and Automated Reasoning	3
CS 205A	Mathematical Methods for Robotics, Vision, and Graphics	3
CS 221	Artificial Intelligence: Principles and Techniques	3-4
CS 223A	Introduction to Robotics	3
CS 224N	Natural Language Processing with Deep Learning	3-4
CS 224S	Spoken Language Processing	2-4
CS 224U	Natural Language Understanding	3-4
CS 224W	Analysis of Networks	3
CS 227B	General Game Playing	3
CS 229	Machine Learning	3-4
CS 231A	Computer Vision: From 3D Reconstruction to Recognition	3
or CS 231B		
CS 234	Reinforcement Learning	3
CS 240	Advanced Topics in Operating Systems	3
CS 240E		
CS 240H		3-4
CS 242	Programming Languages	3
CS 243	Program Analysis and Optimizations	3-4
CS 244	Advanced Topics in Networking	3-4
CS 244B	Distributed Systems	3
CS 244E		
CS 249A		3
CS 270	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	3
CS 273A	The Human Genome Source Code	3
CS 274	Representations and Algorithms for Computational Molecular Biology	3-4
CS 276	Information Retrieval and Web Search	3
CS 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3
CME 108	Introduction to Scientific Computing	3-4
CME 302	Numerical Linear Algebra	3
EE 180	Digital Systems Architecture	3-4
EE 282	Computer Systems Architecture	3

* With consent of faculty adviser.

** Students with equivalent course work may waive with approval of their adviser.

Requirement 4

Additional elective units must be technical courses (numbered 100 or above) related to the degree program and approved by the adviser and MS program administrator. All CS courses numbered above 110 (with the exception of CS 196 and 198) taken for 3 or more units are pre-approved as elective courses. Additionally, up to a maximum of 3 units of 500-level CS seminars, CS 300, EE 380, EE 385A, or other 1-2 unit seminars offered in the School of Engineering may be counted as electives. Elective courses may be taken on a satisfactory/no credit basis provided that a minimum of 36 graded units is presented within the 45-unit program.

Master of Science with Distinction in Research

A student who wishes to pursue the M.S. in CS with distinction in research must first identify a faculty adviser who agrees to supervise and support the research work. The research adviser must be a member of the Academic Council and must hold an appointment in Computer Science. The student and principal adviser must also identify another faculty member, who need not be in the Department of Computer Science, to serve as a secondary adviser and reader for the research report. In addition, the student must complete the following requirements beyond those for the regular M.S. in CS degree:

1. *Research Experience*—The program must include significant research experience at the level of a half-time commitment over the course of three academic quarters. In any given quarter, the half-time research commitment may be satisfied by a 50 percent appointment to a departmentally supported research assistantship, 6 units of independent study (CS 393, CS 395, or CS 399), or a prorated combination of the two (such as a 25 percent research assistantship supplemented by 3 units of independent study). This research must be carried out under the direction of the primary or secondary adviser.
2. *Supervised Writing and Research—I*n addition to the research experience outlined in the previous requirement, students must enroll in at least 3 units of independent research (CS 393, CS 395, or CS 399) under the direction of their primary or secondary adviser. These units should be closely related to the research described in the first requirement, but focused more directly on the preparation of the research report described in the next section. The writing and research units described in parts (1) and (2) may be counted toward the 45 units required for the degree.
3. All independent study units (CS 393, CS 395, CS 399) must be taken for letter grades and a GPA of 3.0 (B) or better must be maintained.
4. *Research Report*—Students must complete a significant report describing their research and its conclusions. The research report represents work that is publishable in a journal or at a high-quality conference, although it is presumably longer and more expansive in scope than a typical conference paper. A copy of the research report must be submitted to the student services office in the department three weeks before the beginning of the examination period in the student's final quarter. Both the primary and secondary adviser must approve the research report before the distinction-in-research designation can be conferred.

Master of Science in Computer Science Education

Candidates for the MS specialization in Computer Science Education will be admitted from a separate pool of applicants and will be eligible only for this specialization. The qualifications for admission are:

- A doctorate in an academic discipline other than Computer Science
- Experience and evidence of excellence in college-level teaching
- Successful completion of a standard introductory programming sequence (CS 106B or equivalent)

Admitted candidates will complete the following courses (45 units) over the course of four quarters:

CS 103, Mathematical Foundations of Computing

CS 107, Computer Organization and Systems

CS 108, Object-oriented Systems Design

CS 109, Introduction to Probability for Computer Scientists

CS 110, Principles of Computer Systems

CS 161, Design and Analysis of Algorithms

CS 198, Teaching Computer Science

CS 208E, Great Ideas in Computer Science

Two CS elective courses and a final project

Admission: In addition to the strong academic preparation required for any graduate program at Stanford, we are looking for candidates who are excellent teachers and who are able to supply evidence of successful university teaching. Applicants should submit a list of courses taught along with the associated teaching evaluations. In addition, applicants should ask their recommenders to concentrate on teaching experience and expertise; recommendation letters that focus on research strengths will carry relatively little weight.

Applications to the MS specialization in Computer Science Education and all supporting documents must be submitted and received online by the published deadline. Information on admission requirements and deadlines is available on the department's web site (http://cs.stanford.edu/admissions/.html).

Joint M.S. and MBA Degree

The joint MS in Computer Science/MBA degree links two of Stanford University's world-class programs. This joint degree offers students an opportunity to develop advanced technical and managerial skills for a broader perspective on both existing technologies and new technology ventures.

Admission to the joint MSCS/MBA program requires that students apply and be accepted independently to both the Computer Science Department in the School of Engineering and the Graduate School of Business. Students may apply concurrently, or elect to begin their course of study in CS and apply to the GSB during their first year.

Additional information on the MS in Computer Science/MBA Joint Degree Program and its requirements is available on the department's web site (https://cs/academics/current-masters/joint-cs-msmba-degree).

Joint M.S. and Law Degree

Law students interested in pursuing an M.S. in Computer Science must apply for admission to the Computer Science Department either (i) concurrently with applying to the Law School; or (ii) after being admitted to the Law School, but no later than the earlier of: (a) the end of the second year of Law School; or (b) the Computer Science Department's admission deadline for the year following that second year of Law School.

In addition to being admitted separately to the Law School and the Computer Science Department, students must secure permission from both academic units to pursue degrees in those units as part of a joint degree program.

J.D./M.S. students may elect to begin their course of study in either the Law School or the Computer Science Department. Faculty advisors from each academic unit participate in the planning and supervising of the student's joint program. Students must be enrolled full-time in the Law School for the first year of law studies. Otherwise, enrollment may be in the graduate school or the Law School, and students may choose courses from either program regardless of where enrolled. Students must satisfy the requirements for both the J.D. degree as specified by the Law School and the M.S. degree as specified in this Bulletin.

The Law School approves courses from the Department of Computer Science that may count toward the J.D. degree, and the Computer Science Department approves courses from the Law School that may count toward the M.S. degree in Computer Science. In either case, approval may consist of a list applicable to all joint-degree students or may be tailored to each individual student program. No more than 45 units of approved courses may be counted toward both degrees. No more than 36 units of courses that originate outside the Law School may count toward the Law degree. To the extent that courses under this joint degree program originate outside of the Law School but count toward the Law degree, the Law School credits permitted under Section 17(1) of the Law School Regulations shall be reduced on a unit-per-unit basis, but not below zero. The maximum number of Law School credits that may be counted toward the M.S. in Computer Science is the greater of: (i) 12 units; or (ii) the maximum number of units from courses outside of the department that M.S. candidates in Computer Science are permitted to count toward the M.S. in the case of a particular student's individual program. Tuition and financial aid arrangements are normally through the school in which the student is then enrolled.

Teaching and Research Assistantships in Computer Science

Graduate student assistantships are available. Half-time assistants receive a tuition scholarship for 8, 9, or 10 units per quarter during the academic year, and in addition receive a monthly stipend.

Duties for half-time assistants during the academic year involve approximately 20 hours of work per week. Course assistants (CAs) help an instructor teach a course by conducting discussion sections, consulting with students, and grading examinations. Research assistants (RAs) help faculty and senior staff members with research in computer science. Many MS students are hired to staff teaching and research assistantships. However, MS students should not plan on being appointed to an assistantship.

Students with fellowships may have the opportunity to supplement their stipends by serving as graduate student assistants.

Doctor of Philosophy in Computer Science

The University's basic requirements for the Ph.D. degree are outlined in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees)" section of this bulletin. Department requirements are stated below.

Requirements

Applications to the Ph.D. program and all supporting documents must be submitted and received online by the published deadline. See the department's web site for admissions requirements and the application deadline (https://cs.stanford.edu/admissions/general-information). Changes or updates to the admission process are posted in September.

The following are general department requirements. Contact the Computer Science Ph.D. administrator for details.

1. A student should plan and complete a coherent program of study covering the basic areas of computer science and related disciplines. The student's adviser has primary responsibility for the adequacy of the program, which is subject to review by the Student Services Office.
2. The first year of the Ph.D. program is spent working with 1-3 different professors on a rotating basis. The intent is to allow the first-year Ph.D. student to work with a variety of professors before aligning with a permanent program adviser. Students who don't need the full year to find a professor to align with will have the option of aligning within the first or second quarter.
3. The CS 300 Departmental Lecture Series seminar gives faculty the opportunity to explain their research to first year CS Ph.D. students. First year CS Ph.D. students are required to attend 2/3 of the classes to receive credit.
4. A student must complete 135 course units for graduation. Computer Science Ph.D. students take 8-10 units per quarter. Credit for coursework done elsewhere (up to the maximum of 45 course units) may be applied to graduation requirements. Students must also take at least three units of coursework from four different faculty members. There are NO courses specifically required by the CS Ph.D. program except for the 1 unit CS 300 Departmental Lecture Series and CS 499 Advanced Reading and Research or its equivalent. At least one course must be taken for a letter grade. A 3.0 GPA must be maintained.
5. Each student, to remain in the Ph.D. program, must satisfy the breadth requirement covering introductory-level graduate material in major areas of computer science. A student must fulfill two breadth-area requirements in each of three general areas by the end of the second year in the program. If students have fulfilled the six breadth-area requirements, and taken courses from at least four different faculty members, they are eligible to apply for candidacy prior to the second year in the program. An up-to-date list of courses that satisfy the breadth requirements (http://cs.stanford.edu/education/phd) can be found on the department's web site. The student must completely satisfy the breadth requirement by the end of the second year in the program and must pass a qualifying exam in the general area of their expected dissertation by the end of the third year in the program.
6. University policy requires that all doctoral students declare candidacy by the end of the sixth quarter in residence, excluding summers. However, after aligning with a permanent adviser, passing six breadth requirements, and taking classes with four different faculty, a student is eligible to file for candidacy prior to the sixth quarter. The candidacy form serves as a "contract" between the department and the student. The department acknowledges that the student is a *bona fide* candidate for the Ph.D. and agrees that the program submitted by the student is sufficient to warrant granting the Ph.D. upon completion. Candidacy expires five years from the date of submission of the candidacy form, rounded to the end of the quarter. In special cases, the department may extend a student's candidacy, but is under no obligation to do so.
7. Each student is required to pass a qualifying exam in their area by the end of their third year in the program. A student may only take the qualifying exam twice. If the student fails the qualifying exam a second time, the Ph.D. program committee is convened to discuss the student's lack of reasonable academic progress. Failing the exam a second time is cause for dismissal from the Computer Science Ph.D. program and the committee meets to discuss the final outcome for the student.
8. As part of the training for the Ph.D., the student is also required to complete at least four units (a unit is ten hours per week for one quarter) as a course assistant or instructor for courses in Computer Science numbered 100 or above.
9. The Reading Committee form and Oral Thesis Proposal must be submitted within one year of passing the qualifying exam.

10. The Oral Thesis Proposal must be submitted before the end of the fourth year.
11. The most important requirement is the dissertation. After passing the required qualifying examination, each student must secure the agreement of a member of the department faculty to act as the dissertation adviser. The dissertation adviser is often the student's program adviser.
12. The student must pass a University oral examination in the form of a defense of the dissertation. This is typically held after all or a substantial portion of the dissertation research has been completed.
13. The student is expected to demonstrate the ability to present scholarly material orally in the dissertation defense.
14. The dissertation must be accepted by a reading committee composed of the principal dissertation adviser, a second member from within the department, and a third member chosen from within or outside of the University. The department requires at least two committee members to be affiliated with the Computer Science department. The principal adviser and at least one of the other committee members must be Academic Council members.

Guidelines for Reasonable Progress

By the end of the first academic year, a student should be aligned with a permanent research advisor.

By Spring Quarter of the second year, a student should complete all six breadth area requirements, two breadth area requirements in each of three areas, and file for candidacy.

By Spring Quarter of the third year, a student should pass a Qualifying Examination (https://cs.stanford.edu/academics/phd/qualifying-exams) in the area of his or her intended dissertation.

Within one year of passing the Qualifying Examination, a student should submit a signed Reading Committee Form (https://stanford.app.box.com/v/docdiss-reading-committee-form).
By Spring Quarter of the fourth year, a student should submit the Thesis Proposal Form (http://cs.stanford.edu/degrees/phd/PhD/ThesisProposalForm.pdf).

The teaching requirement may be satisfied at any time. The research requirement is routinely satisfied by participation in research throughout the student's career.

Ph.D. Minor in Computer Science

For a minor in Computer Science, a candidate must complete 20 units of Computer Science coursework numbered 200 or above, except for the 100-level courses listed on the Ph.D. Minor Worksheet (http://cs.stanford.edu/degrees/phd/admissions/Worksheet.pdf) (pdf). At least three of the courses must be master's core courses to provide breadth and one course numbered 300 or above to provide depth. One of the courses taken must include a significant programming project to demonstrate programming efficiency. Courses must be taken for a letter grade and passed with a grade of 'B' or better. Applications for a minor in Computer Science are submitted at the same time as admission to candidacy.

Emeriti (Professors): Tom Binford, Edward Feigenbaum (http://ksl-web.stanford.edu/people/eaf), Richard Fikes (http://www.stanford.edu/~fikes), Donald E. Knuth (http://www-cs-faculty.stanford.edu/~knuth)*, Jean-Claude Latombe (http://robotics.stanford.edu/~latombe), Marc Levoy (http://graphics.stanford.edu/~levoy)*, Zohar Manna, Teresa Meng (http://dualist.stanford.edu/~thm), William F. Miller, Nils J. Nilsson (http://robotics.stanford.edu/~nilsson), Serge Plotkin (http://troll-w.stanford.edu/plotkin), Vaughan Pratt (http://boole.stanford.edu/pratt.html)*, Eric Roberts (http://cs.stanford.edu/people/eroberts)*, Yoav Shoham (http://robotics.stanford.edu/~shoham), Jeffrey D. Ullman (http://infolab.stanford.edu/~ullman), Gio Wiederhold (http://infolab.stanford.edu/people/gio.html), Terry Winograd (http://hci.stanford.edu/winograd), Ken Salisbury (https://profiles.stanford.edu/john-salisbury), David Dill (https://profiles.stanford.edu/david-dill)*

Chair: Alex Aiken (http://theory.stanford.edu/~aiken)

Associate Chair for Education: Mehran Sahami (http://robotics.stanford.edu/users/sahami/bio.html)

Professors: Maneesh Agrawala (http://graphics.stanford.edu/~maneesh), Alex Aiken (http://theory.stanford.edu/~aiken), Serafim Batzoglou (http://www.serafimb.org/people.html), Dan Boneh (http://crypto.stanford.edu/~dabo), Moses Charikar, David Cheriton (http://www.stanford.edu/~cheriton), David Dill (http://verify.stanford.edu/dill), Ronald P. Fedkiw (http://physbam.stanford.edu/~fedkiw), Hector Garcia-Molina (http://infolab.stanford.edu/people/hector.html), Leonidas J. Guibas (http://geometry.stanford.edu/member/guibas), Patrick Hanrahan (http://www-graphics.stanford.edu/~hanrahan), John Hennessy, Mark A. Horowitz (http://www-vlsi.stanford.edu/~horowitz), Doug James (http://www.cs.cornell.edu/~djames), Dan Jurafsky (http://web.stanford.edu/~jurafsky), Oussama Khatib (http://robotics.stanford.edu/~ok), Monica Lam (http://suif.stanford.edu/~lam), James Landay (https://profiles.stanford.edu/james-landay), Nick McKeown (http://tiny-tera.stanford.edu/~nickm), Christopher Manning (http://nlp.stanford.edu/~manning), David Mazieres (http://www.scs.stanford.edu/~dm), John Mitchell (http://theory.stanford.edu/people/jcm/home.html), Kunle Olukotun (http://ogun.stanford.edu/~kunle), John Ousterhout (http://www.stanford.edu/~ouster/cgi-bin/home.php), Balaji Prabhakar (http://www.stanford.edu/~balaji), Omer Reingold (https://profiles.stanford.edu/omer-reingold), Mendel Rosenblum (http://web.stanford.edu/~mendel), Jennifer Widom (http://infolab.stanford.edu/~widom), Tim Roughgarden (http://theory.stanford.edu/~tim), Subhasish Mitra (http://www.stanford.edu/~subh)

Associate Professors: Gill Bejerano (http://bejerano.stanford.edu), Ron Dror (http://cs.stanford.edu/people/rondror), Dawson Engler (http://www.stanford.edu/~engler), Michael Genesereth (http://logic.stanford.edu/people/genesereth/genesereth.html), Christoforos Kozyrakis (http://csl.stanford.edu/~christos), Jure Leskovec (http://cs.stanford.edu/people/jure), Philip Levis (http://csl.stanford.edu/~pal), Fei-Fei Li (http://vision.stanford.edu), Christopher Re (http://cs.stanford.edu/people/chrismre), Silvio Savarese (http://cvgl.stanford.edu/silvio), Sachin Katti (http://web.stanford.edu/~skatti), Noah Goodman (http://cocolab.stanford.edu/ndg.html)

Assistant Professors: Michael Bernstein (http://people.csail.mit.edu/msbernst), Stefano Ermon (http://cs.stanford.edu/~ermon), Anshul Kundaje (https://sites.google.com/site/anshulkundaje), Percy Liang (http://cs.stanford.edu/~pliang), Greg Valiant (http://theory.stanford.edu/~valiant), Keith Winstein (http://web.mit.edu/keithw), Mary Wootters, Matei Zaharia, Emma Brunskill (https://profiles.stanford.edu/emma-brunskill?tab=bio), Jeannette Bogh, Dorsa Sadigh, Kayvon Fatahalian

Professors (Research): Clark Barrett (http://www.cs.nyu.edu/~barrett), William J. Dally (http://cva.stanford.edu/billd_webpage_new.html),

Professor (Teaching): Mehran Sahami (http://robotics.stanford.edu/users/sahami/bio.html)

Associate Professor (Teaching):

Courtesy Professors: Russ Altman (http://bmir.stanford.edu/people/view.php/russ_b_altman), Stephen Boyd (http://www.stanford.edu/~boyd), Patrick Hayden, Michael Levitt, Roy Pea

Courtesy Associate Professors: Ashish Goel (http://www.stanford.edu/~ashishg), Justin Grimmer, Allison Okamura, Chris Potts, Ge Wang (https://ccrma.stanford.edu/~ge),

Courtesy Assistant Professors: John Duchi, Sean Follmer, Sharad Goel, Thomas Icard, Ramesh Johari, Mykel Kochenderfer (http://mykel.kochenderfer.com), Stephen Montgomery (http://montgomerylab.stanford.edu), Camille Utterback, Gordon Wetzstein, Aaron Sidford, Dan Yamins, James Zou

Lecturers: Gerald Cain, Chris Gregg, Victoria Kirst, Cynthia Lee, Nicholas J. Parlante (http://www-cs-faculty.stanford.edu/~nick), Chris Piech, Keith Schwarz, Marty Stepp (http://www.martystepp.com), Patrick Young (http://www.stanford.edu/~psyoung), Julie Zelenski (http://www-cs-faculty.stanford.edu/~zelenski)

Adjunct Professors: Pei Cao, Stuart Card, Tom Dean, Daphne Koller, P. Pandurang Nayak, Andrew Ng (http://www.andrewng.org), Bill MacCartney (http://nlp.stanford.edu/~wcmac), Sebastian Thrun (http://robots.stanford.edu)

*Visiting Professors:*Thomas Funkhouser

Visiting Assistant Professors:

Secondary Appointment in CS: Anshul Kundaje

* Recalled to active duty.