

# CSE Graduate Student Handbook



**M.S. and Ph.D. Programs in the  
School of Computational  
Science and Engineering**

# **W E L C O M E !**

**Fall, 2019**

**TO:** New Graduate Students

**FROM:** Ümit V. Çatalyürek

Director of the CSE Graduate Programs

This handbook is your guide to the Computational Science and Engineering (CSE) Graduate Programs at Georgia Tech. The CSE Programs include the Master of Science degree program (CSE M.S.) and the Doctor of Philosophy degree program (CSE Ph.D.).

We have prepared this handbook for currently enrolled students, but prospective students should also find it helpful.

If you have questions about any of the material in this handbook, please email

[cse-advisor@cc.gatech.edu](mailto:cse-advisor@cc.gatech.edu) or drop by to see Ms. Nirvana Edwards the CSE Academic Program Coordinator in the Klaus Advanced Computing Building, Room 1120, or consult the Home Unit Coordinators section of this handbook to find the right person for your questions or comments.

On behalf of the entire CSE Graduate Programs faculty, staff, and students, we are pleased that you have joined the CSE family and wish you success in your graduate studies.

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## PROGRAM DESCRIPTION AND OBJECTIVES

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Computational science and engineering (CSE) is the systematic study of computer–based models of natural phenomena and engineered systems. Students, researchers, and practitioners of CSE master domain–independent ideas that cut across computer science, applied mathematics, statistical data analysis and data mining, and the science and engineering disciplines. They use these ideas to solve problems having great societal impact, such as how to grow cities sustainably; how to design of power– efficient buildings and aircraft; how to discover new materials with specific properties; or how to create novel biomedical devices, effective drugs, and efficient health care delivery systems; to name just a few.

The goal of the CSE Graduate Programs (“CSE Programs”) at Georgia Tech is to help you master the unique body of knowledge and professional practices that constitute CSE, working in multidisciplinary teams of faculty and students who have a deep common interest in computational and data–driven models.

More specifically, the CSE programs aim to help you

- master and advance the state of knowledge and/or practice in the computational science and engineering discipline;
- integrate and apply principles from mathematics, science, engineering, and computing to innovate, create computational models, and apply them to solve real–world problems;
- work in multidisciplinary teams of individuals whose primary background is in computing, mathematics, and/or particular science or engineering domain; and
- become leaders in industry, government (e.g., national laboratories), and academia, both in terms of knowledge and computational (e.g., software development) skills.

Toward this end, the CSE programs curriculum engages you in a variety of activities designed to achieve the following educational goals. You will

- develop a solid understanding of fundamental principles across a range of core areas in the computational science and engineering discipline;
- develop a deep understanding and set of skills and expertise in a specific computational specialization of the computational science and engineering discipline;
- be able to apply and integrate the knowledge and skills they have developed and demonstrate their expertise and proficiency in an application area of practical importance; and
- be able to engage in multidisciplinary activities by being able to communicate complex ideas in their area of expertise to individuals in other fields. You will also be able to understand complex ideas and concepts from other disciplines, and incorporate these concepts into your own work.

## DESIRED QUALIFICATION OF STUDENTS

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Students admitted to the program must be able to demonstrate the following competencies:

- An undergraduate level understanding of concepts from computer science, applied mathematics, statistics, a physical science (e.g., physics, chemistry, or biology), and/or engineering. Typically, a student demonstrates such understanding by a bachelor's degree in one of these subject areas. However, a student with a different background may also apply. The admissions process examines all aspects of the applicant's background, including all work and other academic experience.
- Computing skills in algorithms, data structures, and programming in a language such as C or FORTRAN is required. At a minimum, this requirement is an introductory computer science course or equivalent experience. However, at least two semester courses are strongly recommended, and the more algorithms and programming experience, the better.
- Undergraduate mathematics in calculus is required. Undergraduate course work in areas such as mathematical analysis, numerical differential equations, linear algebra, discrete mathematics, and probability and statistics are also highly recommended, and may be required for certain programs of study selected by the student.
- Students missing one or more of these competencies may still apply. However, they will be expected to fill any gaps in their background by, for instance, completing preparatory coursework upon joining the program.

# HOME UNITS AND HOME UNIT REQUIREMENTS

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As a student in a CSE Program, you must choose a *home unit*. A home unit is an academic unit (Department, Division, or School) at Georgia Tech that has agreed to formally participate in the CSE programs. Each home unit has a *home unit coordinator*, who is a faculty member in that unit.

You and the home unit must mutually agree to your home unit affiliation. An initial home unit is determined during either the admissions process or in the process of transferring to a CSE program from another academic program at Georgia Tech. Once admitted, you may change to a new home unit if that unit agrees.

Each academic unit determines the rules for allocation of space and financial assistance (e.g., teaching and research assistantships) for students homed in that unit. If you are a Ph.D. student, your dissertation advisor should have an appointment in your home unit, in addition to being a member of the CSE programs faculty.

Of course, you are welcome to explore research opportunities with faculty in other units beyond your home unit. If a faculty member in another home unit becomes your advisor, you would normally change your home unit accordingly.

Regardless of your home unit, you must fulfill the degree requirements specified in this document to complete your program. Some home units have additional degree requirements, as summarized below. Be sure that you understand and satisfy these requirements as well.

*Note: If you wish to be homed in a unit not shown here, please contact the CSE Programs Director*

- *School of Aerospace Engineering.*
  - MS students *must* complete the thesis option of the Master's degree program.
- *School of Biological Sciences.*
  - No additional degree requirements are specified.
- *Coulter Department of Biomedical Engineering.*
  - Students must take application specialization courses from the BME department, as approved by the BME home unit coordinator.
  - At least two individuals of the Ph.D. dissertation committee must be faculty members from the Coulter BME Department.
  - The student's principal research advisor must be a member of the Coulter BME Department faculty.
  - PhD students must participate in the BME teaching practicum program, and serve as a teaching assistant in BME courses for two semesters and in the BME seminar course for their first two academic years in residence.
- *School of Chemistry and Biochemistry.*
  - Students must take application specialization courses from the School of Chemistry and Biochemistry, as approved by the school's home unit coordinator. Students should enroll in at least one course offered by the school during each semester in which the student serves as a teaching assistant for the school.

- At least three individuals of the Ph.D. dissertation committee must be faculty members from the School of Chemistry and Biochemistry.
- Beyond the second semester, the student's principal research advisor must be a member of the School of Chemistry and Biochemistry faculty to be eligible to serve as a teaching assistant in that school.
- *School of Civil and Environmental Engineering.*
  - Students must complete a 12-hr specialization in CEE.
- *School of Computational Science and Engineering.*
  - PhD students must fulfill a two-semester teaching apprenticeship.
- *School of Industrial and Systems Engineering.*
  - No additional degree requirements are specified.
- *School of Mathematics.*
  - PhD students must take at least 9 hours having the MATH course designations which are not cross-listed with another department.
  - PhD student's Oral exam format is different (see section on CSE Qualifying Examination).
  - At least one individual of the PhD dissertation committee must be faculty member from the school of Mathematics.



## **PROGRAMS ADMINISTRATION AND POINTS OF CONTACT**

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The CSE Graduate Programs Office administers the programs, in conjunction with administrative personnel from each of the participating units. It coordinates the various program activities and provides a single “interface” to the programs both from outside Georgia Tech as well as within Tech (e.g., the registrar’s office). The *CSE programs director* is a faculty member who has overall responsibility for management and administration.

In addition, each participating unit designates a *Faculty Liaison and a Coordinator*. The faculty liaison is a faculty member with overall responsibilities for CSE programs activities as they pertain to that home unit. The home unit coordinator represents that home unit in administrative activities that pertain to the program as a whole.

You should first consult with your home unit coordinator for advice and recommendations concerning your program, and consult with the CSE programs director as needed.

### **CSE Programs Director**

**Dr. Ümit V. Çatalyürek**

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### **CSE Programs Coordinator**

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## CSE Faculty Liaisons

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### ***Chemistry and Biochemistry***

#### **Dr. C. David Sherrill**

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## CSE Home Unit Coordinators

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## **CSE PROGRAMS FACULTY**

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### **Computational Science and Engineering**

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### **Aerospace Engineering**

PK Yeung, Suresh Menon, Sathya Hanagud, Marilyn J. Smith, Lakshmi Sankar, Karen Feigh, Dimitri Mavris, Graeme Kennedy, Vigor Yang, Eric Feron, Joseph Oefelein, Evangelos Theodorou, Stephen Ruffin, Massimo Ruzzene

### **Biomedical Engineering**

Mark Borodovsky, Melissa Kemp, Robert Lee, Cassie S. Mitchell, Peng Qiu, Eberhard Voit, May Wang, Ajit Yoganathan

### **Civil and Environmental Engineering**

Nelson C. Baker, James David Frost, Aris Georgakakos, Emily Grubert, Michael Hunter, Jorge Laval, Jian Luo, Rafi Muhanna, Phil Roberts, Armistead G. Russell, Don White, Yi-Chang James Tsai

### **Industrial and System Engineering**

Christos Alexopoulos, Dave Goldsman, Seong-Hee Kim, Sigrun Andradottir, Martin Savelsbergh, Craig Tovey, George Nemhauser, Arkadi Nemirovski, Brani Vidakovic, Yao Xie, Tuo Zhao

### **Biological Sciences**

Mark Borodovsky, King Jordan, Joshua Weitz, Soojin Yi

### **Chemistry and Biochemistry**

Ken Brown, David Sherrill, Jean-Luc Brédas

### **Mathematics**

Greg Blekherman, Luca Dieci, Guillermo Goldsztein, Christine Heitsch, Christian Houdre, Sung Ha Kang, Vladimir Koltchinskii, Rachel Kuske, Lew Lefton, Anton Leykin, Wenjing Liao, Yingjie Liu, Rafael De La Llave, John McCuan, Martin Short, Molei Tao, Howard (Howie) Weiss, Haomin Zhou

# MASTER OF SCIENCE DEGREE PROGRAM (M.S. CSE) REQUIREMENTS

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The Master of Science degree in CSE is designed to provide you with (a) a base of knowledge and skills in core CSE areas; (b) in–depth knowledge of advanced computational methods; and (c) experience in applying computational methods to relevant and important problems within the context of at least one specific application domain. The program was also designed for you to flexibly tailor the program to your individual career objectives.

Note: The requirements described below form the general framework of the degree program; within this framework, each home unit may have specific custom rules. Examples appear in the text, but be sure to check for requirements specific to your home unit.

The CSE M.S. requires a minimum of 30 semester hours. (A typical course is 3 semester hours.) Table 1 summarizes these requirements.

**Table 1. Curriculum Overview (30 hours)**

Curriculum Component	Semester Hours
CSE core courses	12
Computation and application specialization – home unit minor	12
Additional computation and application electives (non–thesis option)	6
CSE Thesis (thesis option)	6
<b>Total</b>	<b>30</b>

- The core courses define a core body of knowledge in CSE. You must take 12 hours of core courses.
- The computation and application specialization is a set of technical elective courses that focus on developing a more in–depth knowledge of both computational techniques and the application of computational methods in an application domain. A minimum of one application course must be included in this area.\* This set of courses will typically form a body of material in close alignment with your home unit. It also forms a minor course of study aligned with your home unit. You must take 12 hours of courses to fulfill this requirement.

\*As a guideline, your “Computation Specialization” is supposed to give you more depth in computational techniques; your “Application Specialization” is supposed to give you exposure to one or more application domains in which you could apply those techniques. For example, you might take a course in HPC or machine learning to study general mathematical and algorithmic methods, and then take a course in, say, biology, materials engineering, or finance to learn more about an area in which you might apply such methods. (The course does not have to be about applying the methods; the idea is that you learn enough about some area \*outside\* your computation specialization.) This is just an example; in evaluating your program of study, we will consider reasonable arguments. That’s why we ask you to choose your application specialization course \*and\* explain how it fits this notion of an application specialization.

- Finally, you must complete an additional 6 hours by completing either the thesis option or additional technical electives.
- You must maintain a grade point average (GPA) of at least 3.0 for all courses listed on his/her degree program. All courses listed in the degree program must be taken on the A–F grading basis if the A–F grading basis is offered.
- A M.S. degree must be completed within six years from the date of the first coursework on the degree program, including any transfer credits.

## CSE Core (12 Semester Hours)

To fulfill the core courses requirement, you must complete four courses of the five listed in Table 2. If, prior to entering the program, you have completed a core course or its equivalent course at another institution (subject to approval), you may substitute an additional specialty course for the core course, consistent with your intended specialization.

Five courses comprise the CSE core. These courses have several objectives:

- Provide you with knowledge of a variety of areas within the CSE discipline.
- Ensure you have strong software development skills, so that you can develop substantial computational artifacts.
- Train you to integrate and synthesize concepts from mathematics, computing, science, and engineering to solve computational problems.
- Develop your ability and skills to perform multidisciplinary research involving complex concepts from computing, mathematics, science, and engineering.

**Table 2. CSE Core (12 hours; pick any four courses)**

<b>Core Course Number and Title</b>	<b>Credit Hours</b>
CSE/Math 6643 Numerical Linear Algebra	3
CSE 6140 Computational Science and Engineering Algorithms	3
CSE 6730 Modeling and Simulation: Fundamentals & Implementation	3
CSE/ISYE 6740 Computational Data Analysis	3
CSE 6220 High Performance Computing	3

### **Computation and Application Specialization - Home Unit Minor (12 Semester Hours)**

The Computation and Application Specialization requirement is a set of technical electives that forms a focused area of specialization in CSE in conjunction with your declared home unit. The aims of this specialization are to (1) increase your depth of knowledge and skills in CSE computational techniques, (2) equip you with knowledge of a particular application domain to enable you to attack problems within that domain by applying advanced computational techniques, (3) provide sufficient flexibility for you to tailor course selections to your individual needs and long-term career objectives, and (4) ensure you complete a well-structured, coherent program of study. The specialization requirement is designed to help you develop multidisciplinary skills in at least two areas among computation, science, and engineering.

To fulfill this requirement, you must take an additional 12 hours of courses that meet the following criteria:

- The set of courses must clearly support graduate work in the computational science and engineering discipline.
- The courses must include at least one application domain, in addition to providing advanced knowledge of computational techniques. At least one course applying CSE techniques to a specific domain is necessary to fulfill this requirement.
- The set must include at least 6 hours of coursework offered outside computing (i.e., not carrying a CS or CSE course designation).
- During the first semester of study in the program, you must propose the technical specialization to be applied to your CSE degree. Both the home unit coordinator and CSE programs director must approve it.

There are numerous courses offered at Georgia Tech that are appropriate for “graduate work in the computational science and engineering discipline.” You should consult with your home unit coordinator and/or the CSE programs director for guidance in constructing an appropriate course of study.

Recall that your home unit may impose additional requirements or constraints. For example, if your home unit is the School of Aerospace Engineering, you must take the M.S. Thesis option.

## **Program of Study Approval**

You must obtain approval of your proposed program of study in your first semester of enrollment in the CSE program. Both your home unit coordinator and the CSE programs director must approve it. This approval process is designed to ensure that you have a good plan for meeting the degree requirements, and that your overall program of study is consistent with your intended career objectives.

## **CSE Master's Thesis**

If you wish to carry out graduate-level research on a topic in the CSE discipline, consider the Master's thesis option. This option is a great way to "go deep" on a topic, interact closely with faculty, and build an impactful body of work over multiple semesters.

To complete a M.S. Thesis, you must show that you can perform independent research, in collaboration with a faculty advisor, and you must defend this work to a committee of faculty. More specifically, you must:

- Define a suitable research problem and approach in consultation with a thesis advisor. The thesis advisor should be a faculty member from a unit participating in the CSE program.
- Complete 6 semester hours of the course CSE 7000 (Master's Thesis).
- Document this work in a Master's thesis. Typically, this document describes the research problem, summarizes relevant related work, explains the approach used to attack the problem, presents the results of using this approach, and concludes by speculating on areas or additional follow-on work that merit investigation.
- Defend the research and results of the work to a thesis committee. This committee must include at least three individuals.

Your thesis committee must include at least one faculty member with an appointment in the College of Computing and one with a faculty appointment in the College of Sciences or the College of Engineering. The home unit coordinator and CSE programs director must approve your research problem statement and your list of members of your thesis committee prior to starting the thesis option.

Lastly, note that the campus provides general guidelines relevant to all M.S. thesis degrees. This material includes suggestions about how to register if you are, for instance, a Graduate Research Assistant (GRA), and how to sign up for additional semester hours of independent study, thesis work, or GRA section, as your thesis work may require.

Please see: [Please see: http://www.gradadmiss.gatech.edu/theses-dissertations](http://www.gradadmiss.gatech.edu/theses-dissertations)

## **Obtaining a CSE Master's Degree while Pursuing a Ph.D. Degree**

If you are pursuing a Ph.D. degree, you may obtain a CSE Master's degree if the CSE Master's degree program requirements are fulfilled. See the CSE graduate programs advisor for details.

## **Transfer of Credits**

You must request any transfer of credit during your first semester in residence at Georgia Tech. Per campus rules, you may receive up to six semester hours of transfer credit toward the CSE M.S. degree for graduate-level courses taken at an institution accredited by a Canadian or U.S. regional accrediting board, or at a foreign school or university that has a signed partner agreement with Georgia Tech. You may not use courses for which you receive transfer credit toward another degree unless otherwise specified.

You must ask the CSE programs director whether the courses to be transferred are a logical part of the graduate program at Georgia Tech. You will then need to give the CSE programs advisor a copy of your

current transcript, which should display the course(s), and also provide some descriptive course materials, such as a catalog description, syllabi, exams, assignments, and textbooks — the more information you can provide, the better. The CSE programs director will consult with Georgia Tech faculty in the appropriate area to determine the equivalent Georgia Tech course and the number of credit hours to be accepted. Once the CSE programs director approves the course(s) for transfer credit, the Non– Resident Credit Report is prepared and sent directly to the Georgia Tech Registrar with the supporting documentation.

For more information on transfer of graduate credits, see:

<http://catalog.gatech.edu/academics/graduate/policies-and-regulations/>

## Sample Programs

### Non–Thesis Option

Semester 1 (Fall)	Semester 2 (Spring)	Semester 3 (Fall)
CSE–core (3)	CSE–core (3)	Specialization (3)
CSE–core (3)	CSE–core (3)	Specialization (3)
Specialization (3)	Specialization (3)	Specialization (3)
Specialization (3)		

### Thesis Option

*Note: This table represents a three–semester program; however, most students take four semesters to build up enough background knowledge to successfully complete their thesis research.*

Semester 1 (Fall)	Semester 2 (Spring)	Semester 3 (Fall)
CSE–core (3)	CSE–core (3)	Specialization (3)
CSE–core (3)	CSE–core (3)	Specialization (3)
Specialization (3)	CSE 7000 (MS Thesis) (3)	CSE 7000 (MS Thesis) (3)
Specialization (3)		

# DOCTOR OF PHILOSOPHY (PHD) DEGREE PROGRAM REQUIREMENTS

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The CSE Ph.D. program is designed to provide you with the flexibility to tailor your program of study to your individual career objectives. You define the program of study with the approval of the dissertation advisor, home unit coordinator, and CSE programs director. However, your program of study must also satisfy the minimum course requirements below.

Note: The following discussion describes the general framework of the CSE Ph.D. program requirements; be sure to check for variations specific to your home unit.

The Ph.D. degree in CSE requires a minimum of 31 semester hours of coursework. (A typical course is 3 semester hours.) Table 3 summarizes these requirements. These requirements are designed give you breadth of knowledge in CSE, depth in specific computational methods and techniques, and knowledge to apply these techniques to problems within the context of a specific application domain. The required coursework for CSE Ph.D. program includes:

- *CSE core.* You must take twelve semester hours of CSE core courses. These courses give you breadth of knowledge in the major areas of CSE. These courses provide a base of knowledge and skills spanning several core areas of computational modeling.

In addition, you must take a one-hour introductory course that focuses on an introduction to the CSE discipline and multidisciplinary communications. You should take this course in your first year.

- *Computation specialization.* You must take nine semester hours in a set of courses that help you develop in-depth knowledge of advanced computational methods and techniques.
- *Application specialization.* You must take nine semester hours of courses in an application domain. The purpose of this requirement is for you to acquire sufficient knowledge and experience to apply computational methods to relevant and important problems within the context of such a domain.

In parallel to requirements listed above

- *Special problems.* You must complete one special problems course with a minimum of three semester hours. A special problems course is an independent study course taken under a CSE Programs faculty member. You may apply special problems course hours toward either your computation or application specialization requirements. See below for details.

These requirements constitute the minimum amount of coursework to fulfill degree requirements. Your dissertation advisor and your home unit may impose additional course requirements in accordance with the home unit's rules and with your specific research activities and long-term professional objectives.

You must maintain a GPA of at least 3.3 for all courses listed on your program of study. You must take these courses on an A–F grading basis if offered.

You must complete your Ph.D. degree within ten years from the date of the first coursework on the degree program, including any transfer credits.

You may complete a CSE M.S. degree along the way.

Lastly, the campus provides general guidelines relevant to all Ph.D. degrees. This material explains, for instance, how to register if you are a Graduate Research Assistant (GRA) or Graduate Teaching Assistant (GTA) in a given semester.

Please see: <http://www.policylibrary.gatech.edu/student-affairs/policy-hour-loads-graduate-students>



**Table 3. Curriculum Overview (31 hours)**

Curriculum Component	Semester Hours
CSE 6001 Intro to CSE	1
CSE core courses	12
Computation specialization (may include special problems)	9
Application specialization (may include special problems)	9
<b>Total</b>	<b>31</b>

### Sample Program

The following is a sample program that you might follow to complete your PhD course requirements in two years:

Semester 1 (Fall)	Semester 2 (Spring)	Semester 3 (Fall)	Semester 4 (Spring)
Intro to CSE: CSE 6001 (1)	CSE-core (3)	Specialization (3)	Specialization (3)
CSE-core (3)	CSE-core (3)	Specialization (3)	Specialization (3)
CSE-core (3)	Specialization (3)		
Special problems (3)			

### Computation Specialization (9 Semester Hours)

You must complete nine hours of technical electives focusing on advanced computational methods. This specialization increases your depth of knowledge and skills in computation. The set of computation specialization courses that you take must clearly support graduate work in the CSE discipline. (You justify your chosen courses by arguing how they advance your knowledge of computational techniques and methods relevant to your research.)

Georgia Tech currently offers many courses that involve computational methods. A recommended list of suitable courses and concentrations is included in handbook. You should consult with your research advisor to select a suitable set of courses.

In general, simply using computer software in the course does not qualify the course for the computation specialization. Rather, the course must include intellectual content in computational methods or techniques, ideally in the context of some domain or class of applications. Courses listed under "CSE core" (Table 2) that are not used to satisfy the core course requirement may be used to partially fulfill the computation specialization requirement.

### Application Specialization (9 Semester Hours)

You must complete an additional nine hours of technical electives focusing on an application domain where advanced computational techniques may be applied. Courses fulfilling this requirement need not necessarily have a computation focus. For instance, a course may provide essential background

knowledge of an application area (e.g., a science or an engineering field) that enables you to apply computational techniques in that domain. See application courses section for examples.

Note that the computation and application specialization courses, when taken together, must constitute a coherent program of study. “Coherent” means that there is a strong argument the courses will enable you to develop and apply advanced computational techniques and methods to relevant problems in a specific field of study. Your advisor and the CSE programs director can provide more detailed guidance and feedback.

Additional requirements or restrictions may apply, depending on the home unit. Here is a general guideline for the Application Specialization:

\*As a guideline, your “Computation Specialization” is supposed to give you more depth in computational techniques; your “Application Specialization” is supposed to give you exposure to one or more application domains in which you could apply those techniques. For example, you might take a course in HPC or machine learning to study general mathematical and algorithmic methods, and then take a course in, say, biology, materials engineering, or finance to learn more about an area in which you might apply such methods. (The course does not have to be about applying the methods; the idea is that you learn enough about some area \*outside\* your computation specialization.) This is just an example; in evaluating your program of study, we will consider reasonable arguments. That’s why we ask you to choose your application specialization course \*and\* explain how it fits this notion of an application specialization.

### **Special Problems Requirement (3 to 6 Semester Hours)**

The aim of this requirement is for you to conduct preliminary research with a CSE program faculty member early in the Ph.D. program. As such, we highly recommend you take it in your first semester. You and the supervising faculty member define the work to be done and the terms for successful completion. You must take at least 3 semester hours in one special problems course. You may special problems course hours toward your specialization requirements. However, you may only apply a maximum of 6 semesters hours toward such requirements. (Moreover, you may apply each special problems course toward either your computation specialization or toward your application specialization, but not both.) You must declare your intent in your program of study.

The special problems course number and rules for signing up vary by home unit; for instance, the course is CSE 8903 for students homed in CSE and requires the CSE permit form (available at <http://www.cse.gatech.edu/academics/current-students/forms>) approved by the supervising faculty member.

### **Program of Study Approval**

You must file an approved program of study located on the CSE website indicating which courses will be used to fulfill the degree requirements. You must do so after successfully passing the Qualifying Exam. Your dissertation advisor, the home unit coordinator, and the CSE programs director must approve your proposed program of study.

### **Minor Requirement**

You must complete a focused program of study including at least 9 semester hours of courses outside the computational science and engineering field. These courses will normally consist of courses that carry neither the CSE nor the CS course designation.

The curriculum is inherently multidisciplinary, requiring study in at least two fields (CSE and a domain of application). As such, *courses that do not carry the CS/CSE designation and that are used to fulfill the computation or application specialization requirements may also be used to fulfill the minor requirement.*

### **Ph.D. Annual Review**

PhD students homed in CSE will be reviewed on an annual basis to determine progress and performance in the Ph.D. program.

Details of this review process vary by the home unit. For example, if you are homed in the School of CSE,

you complete a self-evaluation of your performance. Your faculty advisor then reviews your self-evaluation, and submits a recommendation of your status. A Ph.D. Review Committee considers these materials and then assigns you one of five possible status designations: satisfactory, minor concern, concern, warning, and probation. If you do not receive a satisfactory designation, the committee will reevaluate your case in the Spring semester. If you receive a probation status, you are in jeopardy of losing financial support. Furthermore, any student placed on academic probation by the institute, e.g., due to a low GPA, shall automatically be placed on probation status. You should receive the result of the review in writing prior to the end of the Fall semester.

PhD students homed in Math will follow the same review process as PhD in Math students yearly.

## **Teaching Apprenticeships (School of CSE only)**

If your home unit is the School of CSE, you must complete a two-semester teaching apprenticeship. Through this requirement, you will develop general skills in pedagogy, communication, curriculum develop, and organization. This type of practical experience should help you become an effective communicator, regardless of whether you intend to pursue an academic or industrial career. During the semester, you are serving as a teaching apprentice, you must also take an additional seminar course. Please see the Graduate Programs Advisor for additional details. Once you have fulfilled the two-semester requirement, you may apply to work as an instructor for a CSE class.

## **CSE Qualifying Examination**

### ***CSE Ph.D. Qualifying Exam Format***

The Ph.D. qualifying examination is designed to ensure that you have achieved sufficient knowledge in core areas of CSE as well as in your chosen specialization area, as preparation for advanced research. It consists of two parts.

- *Written qualifying exam:* The written exam covers core areas of CSE. You select two areas among the following five: numerical methods, discrete algorithms, modeling and simulation, computational data analysis, and high performance computing. These areas correspond with the five CSE core courses. The written exam includes the topics from these courses, possibly augmented with a reading list provided to the student as preparation for the examination. The format is a day-long written examination.
- *Specialization exam and artifact defense:* This portion of the exam has two purposes: (1) to assess your knowledge in your specialization area and your preparation for advanced research in a computing, engineering, or science discipline; and (2) to check that you can integrate knowledge in mathematical foundations, computational methods, and knowledge in a specific engineering or science discipline to synthesize a concrete “computational artifact,” e.g., a significant computer program.

The written exam is common to all home units. By contrast, each home unit typically has specific requirements for the specialization exam and artifact, as discussed below.

### ***School of Biological Sciences***

The second portion of the qualifying exam will cover both the computational artifact and the student's specialization area of Biological Sciences. This exam will consist of a formal written grant proposal following National Institutes of Health (NIH) or National Science Foundation (NSF) guidelines that will normally outline the student's thesis research proposal. The grant proposal is expected to describe, as part of the preliminary results, the student's prior research and development of a computational artifact that is related to the student's proposed thesis research. It will also include an oral presentation to the student's thesis committee of the student's prior research accomplishments working under the direction of his or her principal research advisor, with the biological research aspects of the work highlighted. The student will then defend the artifact and the thesis proposal, answering questions orally from the committee.

Frequently, the computational artifact will have been developed or will be under development as part of the student's research project. In such cases, the student must be sure to explain the biological relevance

of this work and how it has or will be applied to biological problems. Students will be expected to demonstrate an understanding of basic biological concepts as they relate to their research project. The grant proposal should be submitted to the committee at least two weeks prior to the oral exam.

Finally, completion of the second portion of the qualifying exam fulfills the CSE program requirement for a dissertation proposal defense. Therefore, students homed in the School of Biological Sciences are not required to complete a separate thesis proposal defense in addition to the qualifying examination.

### ***School of Chemistry and Biochemistry***

The specialization and artifact defense is an exam that will cover both the computational artifact and the student's specialization area of Chemistry in a single oral examination session. The computational artifact defense is an oral defense of the artifact (typically a software program developed by the student). The specialization part of the exam will consist of an oral presentation of the student's prior research accomplishments working under the direction of his or her principal research advisor, with the chemical aspects of the work highlighted. The student should also explain the relevance of this research and discuss their current and future research plans. Frequently, the computational artifact will have been developed as part of the student's research project. In such cases, the student must be sure to explain the chemical relevance of this work and how it has or will be applied to chemical problems. Students will be expected to demonstrate an understanding of basic chemical concepts as they relate to their research project. A written description of both the computational artifact and a summary of prior and current research (no more than 10 pages) should be submitted to the committee at least two weeks prior to the oral exam.

### ***School of Computational Science and Engineering***

The oral exam is administered as follows. The first part of the exam is an interactive dialogue that follows up on the written exam and tests the student's preparation in his/her two chosen areas. The second part of the exam is a student presentation of (a) prior and current research accomplishments of the student carried out under the direction of his/her principal research advisor; and (b) a computational artifact created by the student based on the above-mentioned research accomplishments. The student should explain the relevance of this research and discuss his/her current and future research plan.

The student will have created and documented the computational artifact prior to the examination, and must answer questions regarding the artifact itself. For example, the student may be required to describe the purpose of the artifact and assess its strengths, weaknesses, and aspects of its design, such as the choice of computational algorithms or data structures. The student must also submit a written description of both the computational artifact and a summary of prior and current research (no more than 30 pages). The student must send this description to the School of CSE's graduate advisor at least two weeks prior to the oral exam. Committee members may also ask to evaluate the source code comprising the computational artifact, which must also be available two weeks prior to the oral exam.

### ***School of Civil and Environmental Engineering***

The specialization exam and artifact defense will cover both the computational artifact and the student's specialization area within Civil and Environmental Engineering in a single oral examination session. The computational artifact defense is an oral defense of the artifact (typically a software program developed by the student). The specialization part of the exam will consist of an oral presentation of the student's prior research accomplishments working under the direction of his or her principal research advisor, with the CEE specialization aspects of the work highlighted. The student should also explain the relevance of this research and discuss their current and future research plans. Frequently, the computational artifact will have been developed as part of the student's research project. In such cases, the student must be sure to explain the civil and environmental engineering relevance of this work and how it has or will be applied to CEE problems. Students will be expected to demonstrate an understanding of basic CEE concepts as they relate to their research project. A written description of both the computational artifact and a summary of prior and current research (no more than 10 pages) should be submitted to the committee at least two weeks prior to the oral exam.

### ***School of Mathematics***

Written qualifying exam portion will be the same as all CSE students. The oral part of the Qualifying exam can be combined with the Oral Comprehensive exam with an approval of CSE Math home coordinator (a good standing of written qualifying exam). If there are concerns with written qualifying exam (determined by the Math home unit coordinator), the student is required to have a separate oral qualifying exam following the same format of CSE.

There will be one Oral Comprehensive exam for PhD students homed in Math. This covers both a computational artifact and the student's specialization area of Applied and Computational Mathematics. The goal of the exam is for the students to present the chosen topic of their eventual dissertation to a core group of faculty who will likely become part of the Dissertation Committee.

The specialization part of the exam will consist of a report from the student on the research papers read, and research accomplishments to date, highlighting the components related to applied and computational mathematics. It is expected that students will demonstrate an understanding of basic concepts in applied and computational mathematics as they relate to their research project. The students will also be asked to explain the relevance of their specialization in the broad context of the CSE focus. This part of the exam follows the Oral Comprehensive Exam format of the Math PhD program (<http://www.math.gatech.edu/oral-comprehensive-exam>). This is considered to be thesis proposal in the school of Math, and the students will follow the same time line as Math PhD.

In addition, a part of the oral presentation should have a section on computational artifact. The computational artifact part will follow the same format as for all CSE PhD students.

It is expected that the computational artifact will have been developed as part of the student's coursework and directed study under the direction of their advisors. The students will need to explain the relevance of this work in the context of applied and computational mathematics. The students will also need to explain how the computational artifact will be used as a platform for future computational methodology, theory and code developments.

A short description of the computational artifact and a list of selected readings, coursework, and relevant references (not to exceed 5 pages in total) will need to be submitted before the oral exam. After the exam, the students are required to submit the same paper work as PhD in Math (the Oral Comp Form and Oral Comp Survey form) to Math home unit coordinator, in addition to filing all CSE program paper work to CSE department.

### ***Other Home Units***

For information about the qualifying examination for other home units, please contact the home unit coordinator or CSE programs director.

### ***Ph.D. Qualifying Exam Committee***

Your Ph.D. Qualifying Exam Committee consists of your advisor (and co-advisor, if any) and three *additional* faculty members. It must include faculty members who can test you in your two subject areas, not including your advisor. The CSE programs director must approve your proposed committee.

The qualifying exam committee shall be present for the oral portion of the qualifying exam, which will take place after the written examination has been completed. The qualifying exam committee makes an overall recommendation concerning the outcome of the qualifying examination, covering both the written and oral components.

### ***CSE Qualifying Exam Administration***

The written qualifying exam is usually offered in the Fall and Spring semesters, on the last Friday before the week of semester classes starts. If you do not pass the exam after two attempts (or by the end of your second year, in the case of students homed in the School of CSE), you should seek a Master's degree and you will not be able to continue in the CSE Ph.D. program.

If you are homed in the School of CSE, some additional rules apply. You must take the oral portion of the exam in the same semester, but not during the first four weeks of classes during which the written exam is graded. You should schedule the oral portion of the exam in the semester prior to taking the exam, i.e., in the Summer semester if the exam is to be taken in the Fall. You must attempt the qualifying exam by the end of the second year of your enrollment in the CSE Ph.D. program. If you fail the exam on the first try, you

may retake it at most once more and must do so in the next semester when the exam is offered. Finally, you must pass the qualifying exam *as a whole* (both written and oral portions) by the end of the second year of enrollment in the CSE Ph.D. program.

### ***Declare Intent***

If you plan to take the qualifying exam, you must complete the CSE Qualifying Exam Form (CSE 9000 form) and return it to the CSE Graduate Programs Advisor at least 8 weeks prior to the date of the written portion of the exam.

On this form, you will specify:

- Requested Ph.D. Qualifying Exam Committee members.
- Declaration of two core areas among: Numerical Methods, Discrete Algorithms, Modeling and Simulation, Computational Data Analysis, High Performance Computing.

### ***Composition of the Written Qualifying Exam***

The written qualifying exam covers the five core areas, of which you select two: numerical methods, discrete algorithms, modeling and simulation, computational data analysis, and high performance computing. Each of these core areas provides a reading list composed of books and articles, and its scope covers the general topics taught in the corresponding core courses plus more advanced materials and application-oriented special topics (see Appendix A).

The written exam contains four questions from each of the above core areas. Since you will have chosen two areas, your written exam will contain a total of eight questions (four questions from each of these two selected core areas). Of these, you are expected to answer six questions (three questions from each core area) during the written exam.

### ***Grading and Results***

You are expected to answer exactly three questions in each area. If you answer more than three questions in any area, then only the lowest scored three answers will be counted in that area.

If you are homed in the School of CSE, you will not receive any feedback on your written exam prior to the oral exam. (Recall that you always take both exams in the same semester.)

If you are not homed in the School of CSE, there are three possible outcomes for a written exam: “pass”, “conditional pass”, and “fail”. For these students, a “pass” or “conditional pass” will allow the student to go on with the specialization exam and artifact defense. Students with “fail” will need to retake the written exam. The CSE Written Exam Committee determines the result of the written exam. It is responsible for developing and grading the exam.

Regardless of your home unit, your Ph.D. Qualifying Exam Committee determines the final overall outcome based on the results of all the components of your qualify exam. To pass, a majority of your committee members, including at least three individuals, must vote “pass.”

### ***Applying to Ph.D. Candidacy***

After you successfully present your research proposal (i.e., pass your Ph.D. proposal defense), you must petition for admission to Ph.D. candidacy by submitting the Georgia Tech Request for Admission to Ph.D. Candidacy form. To qualify for Ph.D. Candidacy, you must complete all coursework requirements; achieve a satisfactory scholastic record (3.3 GPA); pass the CSE Qualifying Examination; and submit an approved program of study and an approved thesis committee member form to the CSE programs advisor.

### ***CSE Doctoral Dissertation***

Your doctoral dissertation forms a central component of your CSE Ph.D. Through it, you show your

ability to perform independent research, in collaboration with a faculty advisor, which you can defend to a committee of faculty. To complete your dissertation, you must complete three principal milestones:

- *Ph.D. proposal defense.* The aim of the proposal defense is for you to show that you are prepared to carry out a high-quality doctoral dissertation. The proposal defense has two components. First, you must submit a written proposal documenting the research problem being addressed, discussion of related work, discussion of the research approach used to attack the problem, preliminary research results, and plans to complete the doctoral dissertation research. Secondly, you must defend this proposal to the doctoral dissertation committee in an oral defense. The proposal defense should be completed after some preliminary research has been conducted.

For students homed in the School of Biological Sciences, note that this requirement is combined with the second part of the qualifying examination.

- *Ph.D. dissertation.* You must document the body of your research work and your results in a formal dissertation document. Your research advisor (and co-advisor, if applicable) and doctoral dissertation committee must approve the final document. For campus guidelines on formatting, filing, and other logistics of your dissertation, please see: <http://www.gradadmiss.gatech.edu/theses-dissertations>
- *Ph. D. dissertation defense.* You must present an oral defense of the body of work included in the doctoral dissertation to the doctoral dissertation committee.

The doctoral dissertation committee includes at least five individuals and must include a balance of faculty spanning multiple disciplines. Typically, you would satisfy this latter requirement by having at least two members of the committee with an appointment in the College of Computing, and at least two with an appointment in the College of Engineering or the College of Science. Your main Ph.D. advisor should be a member of your home unit and also a member of the CSE programs faculty.

If you declared the School of Chemistry and Biochemistry as your home unit, you must have at least three committee members that are faculty members of the School of Chemistry and Biochemistry.

### **Obtaining a CSE Master's Degree while Pursuing a Ph.D. Degree**

You have the option of obtaining a CSE Master's degree along the way to your Ph.D. once you have fulfilled the CSE M.S. requirements. You simply need to complete the CHANGE OF MAJOR/LEVEL FOR GRADUATE STUDENTS form located at

<http://www.registrar.gatech.edu/docs/pdf/Grad-Major-Level-Form.pdf>

and submit it to the CSE programs advisor, who will check that you may be awarded the CSE M.S.

## SAMPLE COMPUTATION SPECIALIZATION COURSES

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The following is the list of the sample computational specialization courses. The courses are primarily grouped based on the five CSE core areas. (The courses marked with '+' after the course number indicates the CSE core courses.) Courses marked '\*' are offered through the distance learning program at the time of this writing.

### Numerical Computing and Geometric Computing

- CSE/MATH 6643\*+ Numerical Linear Algebra
- CSE/MATH 6644\* Iterative Methods for Systems of Equations
- MATH 6640\* Introduction to Numerical Methods for Partial Differential Equations
- MATH 6641 Advanced Numerical Methods for Partial Differential Equations
- MATH 6645 Numerical Approximation Theory
- MATH 6646 Numerical Methods for Ordinary Differential Equations
- MATH 6647\* Numerical Methods for Dynamical Systems
- ISYE 6669\* Deterministic Optimization
- ISYE 6679\* Computational Methods
- CEE 6507 Nonlinear Finite Element Analysis
- ME 6104\* Computer Aided Design
- ME 6758\* Numerical Methods in ME
- ME/MSE/PTFE 6795 Mathematical, Statistical, and Computational Techniques in Materials Science
- ME 6124 Finite–Element Method: Theory and Practice
- CEE 6507 Nonlinear Finite Element Analysis
- CS 6764 Geometric Modeling

### Computational Data Analysis and Visualization Modeling and Simulation

- CSE/ISyE 6740\*+ Computational Data Analysis
- CSE 6240 Web Search and Text Mining
- CSE 6241 Pattern Matching
- CS 6480 Computer Visualization Techniques
- CS 6485 Visualization Methods for Science and Engineering
- ISYE 6402\* Time Series Analysis
- ISYE 6404 Nonparametric Data Analysis
- ISYE 6414\* Statistical Modeling and Regression Analysis
- ISYE 6416 Computational Statistics
- ISYE 6783\* Financial Data Analysis
- ISYE 7406 Data Mining and Statistical Learning

### Modeling and Simulation

- CSE 6730\*+ Modeling and Simulation: Fundamentals and Implementation
- CSE/INTA 6742 Modeling, Simulation, and Military Gaming
- CSE/CS 6236 Parallel and Distributed Simulation
- ISYE 6644\* Simulation
- ISYE 6650\* Probabilistic Models
- ISYE 6645 Monte Carlo Methods
- MATH 4255\* Monte Carlo Methods
- ISYE 7210 Real–Time Interactive Simulation
- ME 6105 Modeling and Simulation in Design
- AE/ISYE 6779 Dynamic System Simulation and Modeling
- INTA 6004 Modeling, Forecasting and Decision Making



## CSE Algorithms

- CSE 6140\*+ CSE Algorithms
- CSE 6301\* Algorithms for Bioinformatics and Computational Biology
- CS 6505\* Computability, Algorithms, and Complexity
- CS 6550 Design and Analysis of Algorithms
- CS 7510 Graph Algorithms

## High Performance Computing

- CSE 6220\*+ High Performance Computing
- CSE 6221\* Multicore Computing: Concurrency and Parallelism on the Desktop
- CSE/CS 6230\* High Performance Parallel Computing: Tools and Applications
- CSE/CS 6236\* Parallel and Distributed Simulation
- CS 6290 High Performance Computer Architecture
- CS 7110 Parallel Computer Architecture
- CS 7210 Distributed Computing
- ECE 6101 Parallel and Distributed Computer Architecture

## Optimization

- ISYE 6644\* Simulation
- ISYE 6661 Linear Optimization
- ISYE 6662 Discrete Optimization
- ISYE 6663 Nonlinear Optimization
- ISYE 6669\* Deterministic Optimization
- ISYE 6679\* Computational Methods in Operations Research
- MATH 4580\* Linear Programming
- CSE/MATH 6643\*+ Numerical Linear Algebra
- CSE/MATH 6644\* Iterative Methods for Systems of Equations
- MATH 6640\* Introduction to Numerical Methods for Partial Differential Equations
- MATH 6641 Advanced Numerical Methods for Partial Differential Equations
- MATH 6645 Numerical Approximation Theory
- MATH 6646 Numerical Methods for Ordinary Differential Equations
- MATH 6647\* Numerical Methods for Dynamical Systems
- ISYE 6669\* Deterministic Optimization
- ISYE 6679\* Computational Methods
- CEE 6507 Nonlinear Finite Element Analysis
- ME/MSE/PTFE 6795 Mathematical, Statistical, and Computational Techniques in Material Sci.
- ME 6124 Finite-Element Method: Theory and Practice
- CEE 6507 Nonlinear Finite Element Analysis
- CS 6764 Geometric Modeling

## SAMPLE APPLICATION SPECIALIZATION COURSES

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The number and type of CSE related courses in application areas at Georgia Tech is large and varied. You should work with your advisor(s) to formulate sequences of coherent application specialization elective courses that best meet your research topics, objectives, and other goals. The following is a sample list of application specialization courses. The list is by no means exhaustive but is provided to give you some guidance.

### Fluid Dynamics and Turbulence

- AE 6009 Viscous Fluid Flow
- AE 6012\* Turbulent Flows
- AE 6042\* Computational Fluid Dynamics
- AE 6412\* Turbulent Combustion

### Structural Analysis

- CEE 6551 Advanced Strength of Materials
- Nine additional hours in Structural Engineering, Mechanics and Materials (to be approved by CEE advisor)

### Computational Chemistry

- CHEM 6472 Quantum Chemistry and Molecular Spectroscopy
- CHEM 6491 Quantum Mechanics
- CHEM 6485 Computational Chemistry
- CHEM 8873 (temporary number) Computational Chemistry Applied to Electronic and Optical Organic Materials
- CHBE/CHEM/MSE/PTFE 6751 Physical Chemistry of Polymer Solutions CHBE/CHEM/MSE/PTFE 6755 Theoretical Chemistry of Polymers
- CHEM 6481 Statistical Mechanics

### Theoretical Ecology and Evolutionary Modeling

- MATH 4755 Mathematical Biology
- BIOL 6422 Theoretical Ecology
- BIOL 6600 Evolution
- BIOL 7101 Advanced Sensory Ecology

### Bioinformatics

- BIOL 8803 (temporary number) Genomics and Applied Bioinformatics
- BIOL 7023 Bioinformatics
- BIOL 8803 (temporary number) Molecular Evolution
- BIOL 8804 (temporary number) Macromolecular Modeling
- CSE 6301 Algorithms for Bioinformatics and Computational Biology

### Transportation Systems

- CEE 6601 Linear Statistical Models in Transportation
- CEE 6602 Urban Transportation Planning
- CEE 6603 Traffic Engineering

#### Gaming and Defense Modeling and Simulation

- CS 7497 Virtual Environments
- INTA 6004 Modeling, Forecasting and Decision Making
- AE/ISYE 6779 Dynamic System Simulation and Modeling

#### Computational Electromagnetics

- ECE 6350 Applied Electromagnetics
- ECE 6380\* Introduction to Computational Electromagnetics
- ECE 7380 Topics in Computational Electromagnetics

#### Manufacturing and Logistics

- ISYE 6201\* Manufacturing Systems
- ISYE 6202\* Warehousing Systems
- ISYE 6203\* Transportation and Supply Chain Systems

#### Environmental Engineering

- CEE 6310 Physical Principles in Environmental Engineering
- CEE 6311 Biological Principles in Environmental Engineering
- CEE 6312 Chemical Principles in Environmental Engineering

# APPENDIX A – Reading List for Written Qualifying Exam

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## NUMERICAL METHODS

### Faculty

**Edmond Chow**  
Tobin Isaac  
Haesun Park  
Rich Vuduc  
Hongyuan Zha  
Haomin Zhou

Please note that different from previous years and other exams, the Numerical Methods exam starting in Fall 2017 will be a closed book exam and will focus on numerical linear algebra.

### Suggested readings

- Matrix Computations by Golub and van Loan
- Numerical Linear Algebra by Trefethen and Bau

### Other references

- Scientific Computing: An Introductory Survey by Michael T. Heath
- Applied Numerical Linear Algebra by J. W. Demmel

### Required Core Course

- CSE/MATH 6643 Numerical Linear Algebra

### Additional Suggested Background Courses

- CX/MATH 4640 Undergrad Numerical Analysis
- CSE/MATH 6644 Iterative Methods for Systems of Equations

### Main Topics

- Problem conditioning, perturbation theory
- Stability, error analysis
- Floating point computation, parallel computation
- Computational complexity of algorithms
- SVD, QR, and other orthogonal factorizations
- Solving linear least squares problems, including rank deficient problems
- Gaussian elimination
- Iterative methods and their convergence for solving linear systems (Jacobi, Gauss-Seidel, etc.)
- Eigenvalue problems and their solution (symmetric and nonsymmetric)
- Krylov subspace methods for eigenvalues and linear systems (Lanczos, Arnoldi, CG, GMRES)

# DISCRETE ALGORITHMS

## Faculty

Srinivas Aluru  
David Bader  
**Umit Catalyurek**

## Scope

algorithm design (divide and conquer, dynamic programming, greedy, network flows), complexity analysis (running time, space requirements, NP-completeness), experimentation, and optimization (branch and bound, local search, approximation algorithms)

## Suggested readings Book

- (KT) J. Kleinberg and E. Tardos, Algorithm Design, Addison Wesley, 1st ed., 2005 (main reference, key chapters 4,6,7,8,11)
- (CLRS) T. Cormen, C. Leiserson, R. Rivest, and C. Stein. [Introduction to Algorithms](#), MIT Press, 2010.
- (DPV) S. Dasgupta, C. Papadimitriou, and U. Vazirani, Algorithms, McGraw Hill, 2006

## Other relevant material:

- Guy Blelloch, Algorithms in the Real World, Lecture Notes
- D.S. Johnson, A Theoretician's Guide to the Experimental Analysis of Algorithms, in Proceedings of the 5th and 6th DIMACS Implementation Challenges, M. Goldwasser, D. S. Johnson, and C. C. McGeoch, Editors, American Mathematical Society, Providence, 2002.
- Hoos, Holger H., and Thomas Stützle. *Stochastic local search: Foundations and applications*. Elsevier, 2004. (local search, and experimentation)

## Required Core Course

- CSE 6140 Computational Science and Engineering Algorithms

# MODELING AND SIMULATION

## Faculty

**Richard Fujimoto**  
Richard Vuduc

## Scope

- Discrete event simulation methodology
  - Conceptual models (e.g., queueing networks, petri nets, cellular automata), formalisms
  - DES world views and paradigms (e.g., event-oriented, process-oriented, agent-based simulation)
  - Implementation issues (e.g., event list data structures, threads) Random number and random variate generation
  - Input and output analysis
  - Verification and validation
- Parallel discrete event simulation
  - conservative synchronization: Chandy/Misra/Bryant, deadlock detection and recovery, synchronous execution, lookahead
  - optimistic synchronization: Time Warp, GVT algorithms, memory management, limiting optimism
  - hybrid approaches
  - Time parallel simulation
  - Simulation interoperability, High Level Architecture
- Complex systems
  - cellular automata
  - emergence
  - linear analysis
  - bifurcations and chaos
  - power laws, scaling
- Continuous simulation
  - Boundary value problems for ODEs
  - Elliptic and parabolic PDEs
  - Finite difference methods
  - Finite element methods
  - Consistency, convergence, stability

## Suggested readings

### Books

- L. G. Birta and G. Arbez, Modeling and Simulation: Exploring Dynamic System Behavior, Springer, 2007
- R. M. Fujimoto, Parallel and Distributed Simulation Systems, Wiley, 2000.
- H. Sayama, Introduction to the Modeling and Analysis of Complex Systems, Open SUNY Textbooks, 2015 (<http://bingweb.binghamton.edu/~sayama/textbook/>).

### Articles

- S. Robinson, "Conceptual Modeling for Simulation," *Winter Simulation Conference*, December 2013.
- P. L'Ecuyer, "Random Number Generation with Multiple Streams for Sequential and Parallel Computing," *Winter Simulation Conference*, December 2015.
- R. Sargent, "Verifying and Validating Simulation Models," *Winter Simulation Conference*, December 2014.
- D. Jones, "An Empirical Comparison of Priority-Queue and Event Set

Implementations”, *Communications of the ACM*, 29, 4 (April 1986), 300-311.

- W. T. Tang, R.S.M. Goh, L-J. Thng, “Ladder Queue: An O(1) Priority Queue Structure for Large-Scale Discrete Event Simulation,” *ACM Transactions on Modeling and Computer Simulation*, 15, 3 (July 2005), 175-204.
- R. M. Fujimoto, “Research Challenges in Parallel and Distributed Simulation,” *ACM Transactions on Modeling and Computer Simulation*, Vol. 24, No. 4, March 2016.
- R. M. Fujimoto, “Time Management in the High Level Architecture,” *Simulation*, Vol. 71, No. 6, pp. 388-400, December 1998.

Book chapters on continuous simulations

- Chapters 1, 2, 5, 6, *An Introduction to Computer Simulation*, by M. M. Woolfson and G. J. Pert, Oxford, 1999.
- Chapters 1–3,5 *Numerical Solution of Partial Differential Equations*, by K. W. Morton and F. Mayers, Second edition, Cambridge, 2005.

### **Required Core Course**

- CSE 6730 Modeling and Simulation: Fundamentals and Implementation

Other related courses include:

- CSE 6236/CS4230 Parallel & Distributed Simulation Systems
- AE/CS/ISYE 6778 Simulation Systems: Product and Process Life Cycles
- AE/ISYE 6779 Dynamic System Simulation and Modeling
- MATH 6640 Introduction to Numerical Methods for Partial Differential Equations

# HIGH PERFORMANCE COMPUTING

## Faculty

**Srinivas Aluru**  
David Bader  
Umit Catalyurek  
Edmond Chow  
Tobin Isaac  
Richard Vuduc

## Scope

- Parallel algorithms: including prefix sums, sorting, matrix algorithms, FFT, embeddings.
- Parallel architectures and interconnection networks
- Programming models and communication primitives
- Performance metrics and bounds
- Load balancing and scheduling

## Suggested readings

### Books

[Introduction to Parallel Computing](#), by Ananth Grama, Anshul Gupta, George Karypis, and Vipin Kumar, Addison Wesley, 2003.

### Articles

Gustafson, "Reevaluating Amdahl's Law," *Communications of the ACM*, May 1988

Twelve Ways to Fool the Masses When Giving Performance Results on Parallel Computers; by David H. Bailey; *Supercomputing Review*, Aug. 1991, pg. 54–55.

## Required Core Course:

- CSE 6220 High-Performance Computing

## Other related courses include:

- CSE 6230 / CS 6230 High-Performance Computing: Tools and Applications
- CS 6290 High-Performance Computer Architecture



# DATA ANALYSIS

## Faculty

Polo Chau  
Haesun Park  
Le Song  
Jimeng Sun  
**Hongyuan Zha**

## Scope

- Machine learning
- Parameter optimization
- Regression
- Classification
- Dimension reduction
- Manifold learning

## Suggested readings Books

- C. Bishop. *Pattern Recognition and Machine Learning*. Springer, 2006.
- Wasserman. *All of Statistics*. Springer, 2006.
- Hastie et al. *The Elements of Statistical Learning*. Springer, 2001.
- Witten et al. *Managing Gigabytes*. Morgan Kaufmann, 2nd Edition, 1999.

## Required Core Course:

- CSE/ISYE 6740 Computational Data Analysis (CS7641 Machine Learning)

## Other related courses include

- CSE 6240 Web Search and Text Mining
- CSE 6242 Data and Visual Analytics