1993

Academic Programs in Computational Science and Engineering

John R. Rice
Purdue University, jrr@cs.purdue.edu

Report Number:
93-042

Academic Programs in Computational Science and Engineering

John R. Rice

CSD-TR-93-042
July 1993

ACADEMIC PROGRAMS IN COMPUTATIONAL SCIENCE AND ENGINEERING

John R. Rice
Purdue University
July 9, 1993

Abstract

In the past several years a number of new academic programs have appeared which are called Computational Science and Engineering, or something similar. Brief descriptions of thirteen of these are given along with their context and motivation. The programs included are: Clemson University, George Mason University, Mississippi State University, North Carolina State University, Purdue University, Rensselaer Polytechnical Institute, Rice University, Stanford University, Syracuse University, University of California at Davis, University of California at San Diego, University of Michigan, and the University of Utah.

In the past several years a number of new academic programs have appeared which I label as Computational Science and Engineering, or CSE. Brief descriptions of a number of these are given below, but first I describe the context and motivation for these programs.

The basic problem addressed by these programs is the lack of people to tackle the grand computational challenges in engineering and science. Too often we have highly trained engineers/scientists working on CSE projects whose knowledge about computing is at the college sophomore level—or lower. Too often we have highly trained computer scientists whose knowledge about engineering and sciences is at the college sophomore level—or lower. Traditional educational programs in each of these areas stop at the sophomore level — or earlier — in the other area. Further, education tends to be ad hoc, on the job, and self-taught. For computer science, this means that it is hard to find traditionally trained computer scientists who know enough about engineering and science to understand CSE applications. More specifically, by far the most common educational path for CS students avoids science and engineering. Faculty working in CSE areas find that their Ph.D. students often have spent a year either learning about application areas or a year passing courses and exams in topics weakly related to CSE (e.g., abstract algebra for mathematicians, power systems for electrical engineers, theoretical CS for computer scientists).

The CSE programs have risen out of a desire to remedy this situation. The common thread of these programs is that there is both substantial computer science content and substantial engineering/science content. There is a wide variation in the specific nature of the program because they must be adapted to the local faculty interests and university political structure. All involve more than one department and most involve computer sciences. It is indicative of the situation that at some places one can create a CSE program and find no one in the computer science department interested in it. Ideally, one wants the students to learn most of the material from two disciplines. This is unreasonable, so there are hard choices in what material to include. Most of the CSE programs are at the graduate level where flexibility in tailoring educational programs is common.

The CSE programs at about a dozen universities are described below: Clemson University, George Mason University, Mississippi State University, North Carolina State University, Purdue University, Rensselaer Polytechnical Institute, Rice University, Stanford University Syracuse University, University of California at Davis, University of California at San Diego, University of Michigan, and the University of Utah. In most cases, the program description was drafted by the contact persons named at the end of it. The descriptions illustrate both the diversity of the programs and the common thread of combining computer science, engineering, science and applied mathematics in some way.

CLEMSON UNIVERSITY

The Computational Science program at Clemson University was originally developed by R. M. Panoff (Physics), D. E. Stevenson (Computer Science), and D. D. Warner (Mathematical Sciences) in 1988. Currently, the program is primarily centered in computer science and mathematics; it also includes such diverse academic departments as agricultural engineering, physics, and textile chemistry. The philosophy of the program is that computational science is an umbrella for many disciplines rather than a discipline itself. The concept of computational science is centered on applications, algorithms, and architectures. Computational science is holistic science.

Course work is aimed at the senior/postgraduate level. Currently one course is offered, open to all science and engineering students, which uses the mechanism of case study to develop understanding. It emphasizes interdisciplinary group work. For example, the Spring 1993 course has three groups among seven people: CS and physics; physics and agricultural engineering; and CS and textile chemistry. Clemson insists on this sort of arrangement in order to sensitize the students to the problems of interdisciplinary collaboration. The first course focuses on doing classical, easy to understand problems well. A second course is being developed which addresses advanced topics and advanced computer architectures.

Graduate work at Clemson in computational science is accomplished by first gaining admittance to a department at Clemson. This again emphasizes that computational science is only an umbrella. There is a core of courses offered by computer science and mathematical sciences which prepares the student in the relevant fundamentals. For the Ph. D., the doctoral committee is chosen from among those faculty who have an interest in computational science. The dissertation is expected to have a bearing on applications, algorithms, and architectures. The group runs a weekly seminar in computational science; it is currently focusing on development environments and software engineering issues.

The Clemson program is also active outside Clemson. Three of the faculty members are active in an Undergraduate Faculty Enhancement program in computational science. This program is taught using the facilities of the North Carolina Supercomputing Center and the University of North Carolina, Charlotte. The program is based on the course discussed above. The program targets schools in North and South Carolina, especially the Historically Black and Native American institutions. Other projects in computational science include development of the South Carolina Technical School's ability to support state businesses.

For further information, contact: Professor D. E. Stevenson, Department of Computer Science or Professor D. D. Warner, Department of Mathematical Sciences, Clemson University, Clemson, S.C. 29634. Email: steve@cs.clemson.edu, (803) 656-3444, warner@math.clemson.edu, (803) 656-3434.

GEORGE MASON UNIVERSITY

The Institute for Computational Sciences and Informatics has been established to address today's role of computation in science, mathematics and engineering. Computational sciences is defined as the systematic development and application of computing systems and computational solution techniques to models formulated to describe and simulate phenomena of scientific and engineering interest, while informatics is defined as the systematic development and application of computing systems and computational solution techniques to experimentally- analytically- or bibliographically-generated data to extract information of interest in science and engineering. Computing is now part of a triad with theory and experiment as a means of investigation, and it provides insight and leads to understanding that, in many cases, theory or experiment cannot. The multidisciplinary activities of the Institute respond to this new role for computation, and the Institute seeks to integrate computation among the sciences, mathematics, and engineering to produce new knowledge and understanding about, and approaches to, the research and educational possibilities to be found in nature's complex systems.

The Institute offers a Ph.D. degree in computational sciences and informatics. It focuses on a number of specialty areas including biology, chemistry, earth systems and global changes, mathematics, physics, space sciences, and statistics. The program emphasizes three intellectual elements: common computational sciences and informatics topics, computationally intensive courses in specific areas of interest, and doctoral research. The program requires 72 credit hours beyond the baccalaureate degree with the following minimum credit hours in the following:

1. 12 hours of common computational sciences and informatics courses;
2. 12 hours from required courses in one of the areas of interest;
3. 12 hours in electives from specialty courses in one of the areas;
4. 12 hours from either additional computational topics, specialty research, individualized study based on professional experience and research, transfer credit or other electives;
5. 24 in dissertation research.

Students are encouraged to apply their knowledge to a broad range of scientific problems using extensive computational knowledge and techniques missing from the more traditional degree programs in science and mathematics.

Computation is recognized as a central feature of the instructional and research program of the Institute for Computational Science and Informatics. The Institute, therefore, seeks to establish world class computational facilities.

The Institute for Computational Sciences and Informatics is a separate unit which reports to the Provost of George Mason University. It has its own faculty (currently four regular and twelve research or adjunct professors) plus associated faculty from eleven regular departments. The intention is for the program to expand to have about 25 regular faculty and 200-250 Ph.D. students.

For further information, contact: Professor Menas Kafatos, Institute for Computational Sciences and Informatics, George Mason University, Fairfax, VA 22030-4444. (703) 993-1990.

MISSISSIPPI STATE UNIVERSITY

The Graduate Program in Computational Engineering, which includes the Master of Science and the Doctor of Philosophy, is an interdisciplinary program whereby a student may enter into the degree program after having received an undergraduate degree in engineering, mathematics, physics, computer science, or a physical science.

The Computational Engineering Graduate Program is designed to train students in the use of modern advanced computer architectures and software tools in various fields of science and engineering. The main thrust is the fusion of ideas from computer science and applied mathematics with a number of application areas. The program focuses on modern computational techniques, and emphasizes applied mathematics, numerical analysis, and computer science. Demonstrated expertise in some application area such as computational fluid dynamics, computational electromagnetics, computational heat transfer, etc. is required.

The recipient of this degree will be well-trained in the state-of-the-art numerical methods, high performance computer architecture, use of software development tools for parallel and vector computers, and application of these techniques to at least one scientific or engineering area.

For further information, contact: Professor Jerry Rogers, Department of Electrical and Computer Engineering, Mississippi State University, Mississippi State, MS 39762. Email: rogers@ee.msstate.edu, (601) 325-3912.

NORTH CAROLINA STATE UNIVERSITY

Well-known national influences and initiatives, strong local institutional support and excellent faculty from several departments have propelled high performance computing research and teaching at North Carolina State University. Several shared memory and message passing parallel computers are available on campus for researchers and graduate students, and a Cray Y-MP 8/464 and a Kendall Square KSR2-48 are at the North Carolina Supercomputer Center in Research Triangle Park. This center is managed by the Microelectronics Center of North Carolina and are available using a high speed educational network connecting more than a dozen campuses. At North Carolina State the Center for Research in Scientific Computation (jointly formed by Computer Science and Mathematics) acts as a focal point for academic programs in scientific computing degree programs.

Academic programs at North Carolina State include Computational Mathematics (CMA) within the mathematics department, Scientific Computing (SC) within computer science and Computational Engineering and Science (CES). The latter provides a well structured, expanded, split minor in math and computer science and is available in all engineering and physical science graduate programs. Computer science is a vital component of the research and teaching of scientific computing at North Carolina State, e.g., of the 23 courses that support the CES program, 18 are computer science, with 8 of these cross listed with mathematics.

The SC and CMA programs are very similar and lead to M.S. and Ph.D. degrees in Computer Science and Applied Mathematics. The CES program replaces the minor requirement and is available in all engineering and science departments at the M.S. and Ph.D. levels. With proper advising, a de facto scientific computation track is available within the computer science undergraduate program. North Carolina State's success is being strongly influenced by the cooperative efforts of our computer science and applied mathematics faculties despite being in different colleges. North Carolina State University has a superior reputation in interdisciplinary research.

Complete descriptions of the CES, CMA and SC programs is available from Professor Robert E. Funderlic, Department of Computer Science, North Carolina State University, Raleigh, NC 27695-8206. Email: ref@adm.csc.ncsu.edu, (919) 515-7775.

PURDUE UNIVERSITY

Purdue is in the process of establishing interdisciplinary M.S. and Ph.D. degree programs in Computational Science and Engineering. All fifteen departments of the School of Science and the Schools of Engineering are involved, plus the Departments of Industrial and Physical Pharmacy, Medicinal Chemistry and Pharmacognosy, Psychology, and Sociology/Anthropology. The basic structure of the program is to have students take 70% of their work and exams in a home department and 30% from Computational Science and Engineering (CSE). Students in computer science or computer engineering take a "reversed" program with 30% of their work and exams in one other department.

The Computational Science and Engineering program at Purdue will provide students with the opportunity to study a specific science or engineering discipline along with computer science in a multi-disciplinary environment. The aim of the program is not to produce a student with parts of two degrees, but rather a student who has learned how to integrate computational science with another scientific or engineering discipline. The expected course load and exams for students in this program are roughly the same as masters or doctoral degrees in other disciplines at Purdue, with approximately one third of the course load and exam committees from the computer science department and two thirds in the students "home" department (for students whose home department is Computer Science or Computer Engineering (within Electrical Engineering) the reverse will be true). M.S. students will be well prepared to join and make significant contributions to interdisciplinary research teams. Ph.D. students are expected to become leaders in research and development at the forefront of their field, applying advanced computational techniques and theory to solve key problems. Additionally, it is hoped that this program will foster interaction between faculty and students from the various departments through colloquia and team research efforts.

Four courses form the core of the CSE part of the program: Computational Methods in Linear Algebra, Computational Methods in Analysis, High Performance Computing, and Computational Science and Engineering. The latter is a new graduate course which surveys relevant material about computer systems, programming languages, software engineering, etc. There are many existing, more specialized, courses offered by various departments that are very appropriate for students in the CSE program.

Parallel and vector computers of the Purdue University Computing Center, the Computer Sciences Department, and the School of Electrical Engineering support this program. In addition, a CSE laboratory with multimedia workstations will be established and partially dedicated to support the courses.

The program is operated by its Graduate Committee with one representative from each participating department assisted by a very small staff. This committee has subcommittees which do the actual work. The chair of the committee is the head of the program. The program is governed by its Advisory Committee which consists of the heads of the participating departments. The degrees are awarded by these departments and thus they have control of the curriculum of their students. The student's transcript contains the line *area of specialization* below the line specifying the field of study (the home department) which indicates that the student completed the interdisciplinary CSE program.

For further information contact: Professor John R. Rice, Head, Department of Computer Sciences, Purdue University, W. Lafayette, IN 47907-1398. Email: rice@cs.purdue.edu, (317) 494-6003.

RENSSELAER POLYTECHNIC INSTITUTE

The Computational Science and Engineering program at the Rensselaer Polytechnic Institute is being organized by an interdisciplinary committee chaired by Joseph E. Flaherty (Computer Science) and consisting of Kenneth A. Conner (Electrical, Computer and Systems Engineering), Chun Ming Leung (Physics), Robert G. Loewy (Mechanical Engineering, Aeronautical Engineering, and Mechanics), Kenneth J. Miller (Chemistry), and Mark S. Shephard (Civil Engineering). The program, which will begin admitting students in 1994, is administered by Rensselaer's interdisciplinary Scientific Computation Research Center (SCOREC). Initially focusing on Master of Science and Doctor of Philosophy programs, undergraduate concentrations and minors will be introduced shortly thereafter.

Computational Science and Engineering students will be associated with a "home department" within Rensselaer's Schools of Science or Engineering as appropriate to their major interest. They will take a core of Computer Science and Mathematics courses that includes numerical analysis and scientific computation. Beyond this core, students will select their curriculum as appropriate to their major field. Thus, students not in computer science or mathematics select a curriculum consisting of (approximately one quarter) core courses and (approximately three quarters) specialized science and/or engineering courses. Students having computer science or mathematics as home departments follow a slightly different path by taking approximately one quarter of their courses in an area of natural science or engineering.

Students will become part of an outstanding environment for computational research and education at Rensselaer. A strong group of fifteen science and engineering faculty are unified as members of SCOREC. Created in 1990 as a joint enterprise of Rensselaer's Schools of Science and Engineering, SCOREC's mission is to (i) improve understanding of physical phenomena, (ii) provide new algorithms and solution techniques, and (iii) support computational experimentation. The group's activities are varied, but SCOREC's central objective is algorithm development for (i) the reliable and automatic solution of problems involving partial differential equations, (ii) parallel computational techniques and programming methodology, and (iii) optimal solution procedures for critical applications.

For further information, contact Joseph E. Flaherty, Amos Eaton Professor of Computer Science, Rensselaer Polytechnic Institute, Troy, New York 12180. Email: flaherje@lotus.cs.rpi.edu, (518) 276-6348.

RICE UNIVERSITY

As a consequence of the rapid increase in computing power over the past decade, modern science and engineering have become increasingly reliant upon computation as an aid to research, development and design. Indeed, one can hardly imagine a large-scale engineering project that will not call upon some aspect of the mathematical and computational sciences. However, using the newest and most powerful computers requires a knowledge of parallel and vector capabilities along with a variety of other things such as visualization, networking, and programming environments. In addition, new algorithms and analytic techniques have been developed which enhance the power of these computational tools. The obvious relevance of these techniques to science and engineering has led to the establishment of a focused program in this area at Rice University that can provide specialized training in the use of high performance computing technology.

The Mathematical Sciences Department, in conjunction with the Computer Science, Chemical Engineering, and Electrical Engineering Departments had initiated a new degree program leading to advanced degrees in Computational Science and Engineering (CSE). The program focuses on modern computational techniques and provides a resource of training and expertise in this area. The program is designed to provide this training throughout the university at the Masters and Ph.D. levels.

The program is governed by a committee of faculty chosen by the Dean of Engineering, with ultimate oversight by the Provost. This Computational Science Committee (CSC) is responsible for assisting the student in designing an appropriate course of study, setting examination requirements, and insuring the integrity of the degree program. The CSC is not a new department, but rather a mechanism for initiating the inter-disciplinary research required to advance computational science.

The Professional Masters Degree is intended to produce an expert in scientific computing who can work as part of an interdisciplinary research team. A recipient of this degree will be well trained in state of the art numerical methods, high performance computer architectures, use of software development tools for parallel and vector computers, and in the application of these techniques to at least one scientific or engineering area. The curriculum for this degree consists of a variety of topics from mathematical sciences, computer science, and a selected application area. Requirements include successful completion of 30 semester hours or more of advanced courses. There is no thesis requirement. The program of study will be designed by the student with advice and approval of the CSC.

It has been possible to construct this program from existing courses with one exception. A new course called Introduction to Computational Science has been introduced to serve as the central core course of the program. This one semester course is an introductory survey of the topics that make up the program in scientific computing. Its intent is to aid the students to appreciate the scope of the program so they will be better prepared to design an effective individual selection of later courses. It also serves broader needs of the engineering school and the physical sciences by introducing their students to state of the art technology in scientific computing.

The Ph.D. Degree Program starts with advancement to doctoral candidacy by the successful completion of a program of approved course work along with satisfactory performance on preliminary and qualifying examinations. The foreign language requirements of the student's department will be adhered to. The student must complete an original thesis under the direction of a member of the participating faculty of the CSE program which is acceptable to the Computational Science Committee.

For further information, contact Professors Danny Sorensen or Richard Tapia, Department of Mathematical Sciences, Rice University, Houston, TX 77251. Email: sorensen@rice.edu, (713) 285-5193, rat@rice.edu, (713) 527-4049.

STANFORD UNIVERSITY

Since 1989 Stanford has had a program in place for granting degrees in Scientific Computing and Computational Mathematics. The program is interdisciplinary and can admit students and grant degrees. The purpose of this program is to train students in the use of modern advanced computer architectures and software tools in various fields of science and engineering. The main thrust is the fusion of ideas from computer science and applied mathematics with a number of application areas. The inception of this new program has been motivated in part by the apparent waning interest and support for numerical analysis and scientific computing within the Computer Science Department.

The Scientific Computing and Computational Mathematics program currently resides in the School of Engineering. Students are admitted directly into the program independent of other departments. The Faculty is made up of faculty from other departments and is comprised of three levels of participation. There is the Core faculty including J. Keller, J. Oliger, G. Golub who are responsible for administration; the Associate faculty consisting of people who are heavily involved in computing within their discipline and who offer courses within the program; Affiliated faculty whose disciplines rely on computing to some extent.

Although the program was formally approved in 1987, 1989-90 marked the first year of operation. There were 40 applicants with 10 finally entering the program. Primarily, the applicants were from engineering fields. However, there were also applicants from a variety of other fields including a medical doctor. As of the opening of the '90-'91 academic year, there were 18 students enrolled in the program.

The curriculum emphasizes applied mathematics, numerical analysis, computer science and requires demonstrated expertise in some application area such as fluid mechanics. In addition to this, there are working relationships with local research institutes such as RIACS, LLNL, and IBM.

Further information is available from Professor Gene Golub, Department of Computer Sciences, Stanford University, Stanford, CA 94305. Email: golub@patience.stanford.edu, (415) 723-3125.

SYRACUSE UNIVERSITY

For the past two years, a group of faculty from several departments at Syracuse have been developing programs in which undergraduate and graduate students can combine the study of computer science with an engineering or scientific area. This new interdisciplinary area of study is called Computational Science and involves faculty from computer science, computer engineering, mathematics, physics, chemistry, mechanical engineering, and neuroscience. The programs are administered by the School of Computer and Information Science in the College of Engineering and Computer Science. The new programs draw on many existing courses in applied mathematics, computational techniques for science and engineering areas, and computer science, especially those relating to high performance computing. New courses are also being developed which show directly the interplay between these topics.

It is the intent of the Computational Science faculty to design a full range of academic programs. Currently, programs have been approved at Syracuse in which students in any field can obtain a minor in computational science. At the undergraduate level, the minor is called a *Concentration* *in Computational Science* and consists of a 8 credit two semester sequence of lecture and lab called Introduction to Computational Science and Scientific Programming plus 10 upper division credits of electives, which may include the Senior Computational Science Project.

At the graduate level, the minor is called a *Certificate in Computational Science.* A master's certificate consists of five courses: Introduction to Computational Science, a course in high performance computing, a course in computational techniques of a science or engineering application area, a course in numerical techniques, and an elective. A doctoral certificate requires an additional elective, that the dissertation be supervised by a member of the Computational Science faculty, and that the dissertation make a contribution to the field of computational science.

The Computational Science Curriculum Committee is designing separate degree programs for a B.S., M.S., or Ph.D. in Computational Science. These must be approved by New York State.

Both the undergraduate and graduate computational science programs feature recently introduced courses called Introduction to Computational Science. The content of these courses are organized by modules which cover typical application areas that require computation for solutions in particle systems, field simulations, statistical techniques and optimization problems. Each module includes an introduction to the typical engineering or scientific problem, the numerical methods suitable for solving the problem, the computational algorithms which carry out the method, the issues of high performance computing for those algorithms, and how the resulting computation can be used in specific problems. Another new graduate course, Case Studies in Computational Science, is being offered which concentrates on a more in-depth treatment of computational techniques for statistical treatment of large data, computational fluid dynamics, and statistical physics.

The program is supported by the computing resources of the Northeast Parallel Architectures Center (NPAC). Current machines include a CM5, a DECmpp, an Ncube-2, and an iPSC/860.

For more information, contact Geoffrey Fox or Nancy McCracken, School of Computer and Information Science, Syracuse University, Syracuse NY 13244. Email: gcf@npac.syr.edu, njm@npac.syr.edu, (315) 443-2368.

UNIVERSITY OF CALIFORNIA AT DAVIS

A program of Computational Science has been initiated within the Departments of Applied Science and Chemistry. The reason for starting such a program is the recognition of the fact that computing has emerged as a third way of doing science, complementing the time-honored theoretical and experimental approaches. The computational approach to science has made significant contributions in several disciplines such as aerodynamics, meteorology and nuclear engineering, where previously intractable problems have been solved. Great promise and future growth lie in other disciplines such as molecular biology, material science, chemistry, and physics. The possibilities opened up by the availability of high-speed computing have many similarities across scientific disciplines so that a science of computation does exist.

Questions of science, computational techniques, computer science, and mathematics are inseparable in addressing the large issues in Computational Science. A practitioner of computational science must have some skills in each of these areas and be able to interact from all these areas. Computational Science at U.C.–Davis was established with this philosophy in mind.

Computational Science at U.C.–Davis is designed for the graduate student who is interested in the application of computers to the physical, chemical, mathematical and engineering sciences. The program involves course work from the traditional areas of physics, chemistry, computational mathematics, and computer science as well as in the area of the student's specialization. Ph. D. candidates in participating departments declare a designated emphasis in computational science then proceed to take a special set of core courses in the department in which the student is enrolled and also a set of core courses in computational science. For example, in the Department of Applied Science, the core courses are Mathematical Physics, Computational Mathematics, and a course called Computational Science that is designed especially for physical scientists and which covers such topics as computer architecture with emphasis on parallel computers, algorithms, and numerical methods. After passing a written/oral examination, the student then proceeds to their graduate research by taking electives from a variety of available courses within their department. The degree awarded to the student is: *Doctor of Philosophy in '(department)' with emphasis in Computational Science.*

For additional information contact Professor Gary Rodrigue, Department of Applied Science, University of California at Davis, Davis, CA 95616. Email: rodrigue@lll-crg.llnl.gov, (510) 422-9787.

UNIVERSITY OF CALIFORNIA AT SAN DIEGO

The discipline of scientific computation involves the formulation, analysis and application of computational algorithms for the numerical solution of problems arising in science and engineering. An important characteristic of the discipline is the involvement of high-performance computing in both the theoretical and practical aspects of the research. Scientific calculations generally take two forms, which we have grouped together under the generic title of "scientific computation". *Computation* involves the formulation, analysis and application of computational algorithms for the numerical solution of mathematical models (e.g., finite-element methods for computational fluid dynamics, algorithms for image processing, or combinatorial optimization algorithms for circuit design). *Simulation* includes the mathematical modeling of simplified processes in order to represent real-world processes and systems on a computer, (e.g., rush-hour traffic in a metropolitan area, the real-time operations of a large telephone network, or the flow of air around an aircraft). Computation plays a role in simulation, but the distinction between simulation and computation used here is that a correct simulation must agree with the real world process being considered, whereas a valid computation must agree only with the mathematical model or equation being solved.

As computer problem-solving techniques have advanced over the past forty years, an enormous number of problems that were once considered intractable can now be solved. An inevitable consequence of this success is that there has been a change in the role of computation in research. Scientific computation has moved from being an adjunct to the theoretical investigation, to being the principal means by which the research is performed. Along with the ability to solve increasingly complex problems has come the need to train persons in the *science of computation*. Ad hoc computing techniques have evolved into sophisticated problem-solving tools that require a greater understanding of computer hardware and software than was necessary in the past.

The planned Ph.D. program focuses on areas of scientific computation that have significant overlap with the physical and mathematical sciences and engineering. Students in the program will reside in a home department. They will meet all the requirements of their home department, but take at least 20 units of elective courses from a *Scientific Computation* core. The program can be summarized as follows.

1. In the early years, basic training within the major discipline of the student is provided by the home department (1–2 years);

2. In the middle years, the student pursues a secondary specialization and participates in the Scientific Computation Seminar (1–2 years);

3. In the final years, dissertation research on a topic in Scientific Computation.

Students enter the program through admission to one of the participating departments, which then serves as their home department and specifies their primary specialization. Students may apply for admission to the Program in Scientific Computation during the spring quarter of the first year of residence at UCSD.

The departments currently participating in the proposal are Applied Mechanics and Engineering Sciences, Biology, Chemistry, Comptuer Science and Engineering, Mathematics and Physics. A typical Ph.D. plan of study might include the following:

Applied Mechanics and Engineering Sciences
- Computational Fluid Dynamics
- Finite Element Methods in Solid Mechanics
- Numerical Methods in Engineering Science
- Advanced Computer Graphics for Engineers and Scientists
- Special Topics in Computational Fluid Dynamics

Computer Science and Engineering
- Parallel Computation
- Parallel and Distributed Computation
- System Support for Parallel Scientific Computation
- Parallel Algorithms

Numerical Analysis/Statistics
- Mathematical Methods in Physics and Engineering
- Numerical Mathematics
- Numerical Optimization
- Numerical Partial Differential Equations
- Scientific Computation
- Applied Statistics

For further information, contact: Professor Philip E. Gill, Department of Mathematics, University of California at San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0112. Email: peg@optimal.ucsd.edu, (619) 534-4879.

THE UNIVERSITY OF MICHIGAN

A doctoral program in Scientific Computing has recently been approved by the University of Michigan. The program is a joint degree program — students pursue their doctoral studies in a home department, typically one of the traditional engineering, science, or mathematics disciplines, and take additional courses in areas such as numerical analysis, scientific computation, applications, or the study of algorithms for advanced computer architectures. This interdisciplinary program is intended for students who will make extensive use of these subjects in their doctoral studies. This program is based on the recognition that a firm knowledge of the science is an essential ingredient for research in scientific computation — students are expected to complete the normal doctoral requirements for their home department as well as additional course requirements in scientific computation, numerical analysis, and algorithms for advanced computer architectures. The title of the degree has ... *and Scientific Computing* appended to the normal title, e.g., Ph.D. Degree in Aerospace Engineering and Scientific Computing.

The Laboratory for Scientific Computation administers the doctoral degree program in scientific computing, in cooperation with the student's home department. The following list of research topics is representative of the many and varied activities in scientific computation available for prospective doctoral students:

- Computational fluid dynamics
- Algorithms for advanced computer architectures
- Computational particle transport
- Computational solid mechanics
- Simulation of semiconductor devices
- Simulation of AIDS transmission
- Simulation of VLSI circuits
- Scientific visualization
- High performance materials
- Molecular dynamics
- Computational chemistry
- Computer-aided molecular design

For additional information, contact: Professor William R. Martin, Director, Laboratory for Scientific Computation, The University of Michigan, Ann Arbor, MI 48109-2104. Email: lasc_info@um.cc.umich.edu, (313) 936-3130.

UNIVERSITY OF UTAH

At the University of Utah, the departments of Computer Science (in the College of Engineering) and Mathematics (within the College of Science) have recently developed a joint Computational Engineering and Science (CES) program. The University of Utah's program is designed for students mostly from within the Colleges of Engineering, Mines, and Science and represents both a meeting place to encourage interdisciplinary education and research among those who study and develop computational techniques for science and engineering applications as well as the mechanism for students to obtain a broader and more comprehensive training in computational science. A primary goal of the CES program is training students in the use of advanced computing hardware, and modern computational, graphical, and mathematical techniques for the solution of problems in science and engineering that are inaccessible without such integrated expertise. Successful completion of the program is acknowledged by a certificate that is issued in addition to the regular graduate degree. At a later stage, the program may grow into an interdisciplinary and cross college graduate degree program.

To obtain a graduate certificate in CES, a student must complete courses in the following areas:

Architectures and Algorithms,
Numerical Analysis and Computation,
Advanced Numerical Analysis and Computation,
Scientific Visualization,
Mathematical Modeling,
Case Studies in Computational Engineering and Science,
Seminar in Computational Engineering and Science.

plus complete a project in CES in an application area which is outside the areas of Mathematics and Computer Science (this will normally be satisfied by the student's thesis).

To train the University's CES students, the Departments of Computer Science and Mathematics are in the process of creating a new CES Laboratory consisting of several high-end graphics workstations and servers joined by high capacity network links. This new computing laboratory will augment other university computing facilities in the Departments of Computer Science and Mathematics as well as at the Utah Supercomputing Institute.

For more information, contact: Chris Johnson, Department of Computer Science, or Peter Alfeld, Department of Mathematics, University of Utah, Salt Lake City, UT, 84112. Email: crj@cs.utah.edu, (801) 581-7705, alfeld@math.utah.edu, (801) 581-6842.

SUMMARY OF CES PROGRAMS

The following tabulates six characteristics of the CES program discussed here:

Degree	Level plus indication of separate degree, a minor, independent certificate or specialty within a department.
Departments	Names of departments involved, are abbreviated.
Administration	The unit or units that actually control the program.
Core	Short list of the principal subject areas.
Precis	Very concise summary of program requirements.
Faculty	Approximate number of faculty involved.

CLEMSON

Degree	M.S. and Ph.D. specialty in departments
Dept	CS, Math, Phys, AgE, Textile Chem
Admin	Collaboration by departments, led by CS and Math
Core	Algorithms, architecture and applications
Precis	CS and Math courses, 2 CSE courses, weekly seminar
Faculty	5—10

GEORGE MASON

Degree	Ph.D. in Computational Science and Informatics
Dept	Institute for Computational Science and Informatics, Bio, Chem, Earth Sci, Math, Phys, Space Sci, Stat
Admin	Separate institute
Core	CSE courses and applications
Precis	72 hours: 25% CES, 50% application area, 25% electives
Faculty	15

MISSISSIPPI STATE

Degree	M.S. and Ph.D. in Computational Engineering
Dept	All engineering, Math, CS
Admin	Separate graduate program
Core	Computational math, computer archaitecture, scientific computing, software tools, applications
Precis	Engineering application of mathematics and computer sciences
Faculty	30

NORTH CAROLINA STATE

Degree #1	B.S., M.S., and Ph.D. in math or computer science
Degree #2	Minor for graduate degrees in science and engineering
Dept	CS and Math
Admin	Computer science and mathematics departments
Core	Scientific computing and computational mathematics
Precis #1	CS and math provide 23 courses, normal degree requirements
Precis #2	One of the minors for science and engineering
Faculty	25—30

PURDUE

Degree	M.S. and Ph.D. specialty in departments
Dept	All science and engineering (15), Psych, Soc & Anthro, Med Chem Phar, Ind Phys Phar, Phar.
Admin	CSE committee has one representative per department
Core	Scientific computing
Precis	70% from home department, 30% from CSE (reversed for computer science and computer engineering)
Faculty	75—100

RPI

Degree	M.S. and Ph.D. specialty in departments, minor for B.S.
Dept	CS, Elect-Comp-Syst Engr, ME-AcroE-Mech, Chem, CE, Math
Admin	Scientific Computation Research Center
Core	Scientific computing and numerical methods
Precis	25% CSE and 75% home department (reversed for CS, Math)
Faculty	15

RICE

Degree	M.S. and Ph.D. in Computational Science and Engineering
Dept	Math Sci, CS, ChemE, EE
Admin	Computational Science Committee
Core	Numerical analysis, scientific computing, architecture, software tools
Precis	Ten courses for M.S., individualized for Ph.D.
Faculty	25—30

STANFORD

Degree	Ph.D. in Scientific Computing and Computational Mathematics
Dept	Separate program
Admin	Separate program
Core	Numerical analysis, applied mathematics, relevant computer science
Precis	Normal degree program covering Math, NA, CS and application
Faculty	Four core, 26 Associate and Affiliate faculty

SYRACUSE

Degree	Graduate and undergraduate minors established, B.S., M.S., and Ph.D. planned.
Dept	CIS, Math, Phys, Chem, ME, CE, Neuroscience
Admin	Computer and Information Sciences department
Core	High performance computing, computer science, applied mathematics
Precis	One year course plus 10 hours for B.S. minor, 5—6 courses for graduate minor.
Faculty	18

UNIVERSITY CALIFORNIA — DAVIS

Degree	Ph.D. in Applied Science with Computational Science specialty
Dept	Applied Science
Admin	Applied Science
Core	Classical, continuum and statistical mechanics; mathematical physics, computational math
Precis	Three CSE courses, three special applications courses, electives, thesis
Faculty	9 core, 35 affiliated

UNIVERSITY CALIFORNIA — SAN DIEGO

Degree	Ph.D. specialty in departments
Dept	Appl. Mech. & Engr. Sci., Bio., Chem., CS&E, Math, Phys.
Admin	Program in Scientific Computation
Core	Algorithms and numerical methods, simulation
Precis	3—5 courses in each of Appl. Mech. & Engr. Sci., CS&E, numerical analysis
Faculty	???

MICHIGAN

Degree	Ph.D. specialty in departments
Dept	All engineering plus Math, Stat, Geology, Phar. and Astron.
Admin	Laboratory for Scientific Computation

Core	Scientific computing, architecture, numerical analysis and parallel algorithms
Precis	Regular department requirement plus courses in scientific computing, advanced architectures, parallel algorithms, and numerical analysis.
Faculty	15—20

UTAH

Degree	Graduate certificate in Computational Engineering and Science
Dept	CS, Math
Admin	Computational Engineering and Science program
Core	Computer science, numerical analysis, modeling, case studies
Precis	Seven specified courses
Faculty	25