UNIVERSITY OF MIAMI
FACULTY SENATE

MEMORANDUM

To: President Edward T. Foote II

From: Steven Green
Chair, Faculty Senate

Date: 31 January 2000

Subject: Faculty Senate Legislation #99012(B)- Establishment of the Department of Computer Science in the College of Arts and Sciences

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The Faculty Senate, at its meeting on 26 January 2000, voted to approve the establishment of the Department of Computer Science in the College of Arts and Sciences. The proposal is attached for your information.

This legislation is now forwarded to you for your action.

SG/kl

cc: Provost Luis Glaser
Dean Kumble Subbaswamy
Alan Zame, Chair

2/3/00

Steve, I approve. Thanks. ETF

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Coral Gables, Florida 33124-4634
305-284-3721
Fax 305-284-5515

CAPSULE: Faculty Senate Legislation # 99012(B)-Establishment of the Department of Computer Science in the College of Arts and Sciences

RESPONSE BY THE PRESIDENT: Approve DATE: 2/3/00

OFFICE OR INDIVIDUAL TO IMPLEMENT: Provost

APPROVED: [signature]

EFFECTIVE DATE OF LEGISLATION: ______

NOT APPROVED AND REFERRED TO: ______

REMARKS (IF NOT APPROVED): ______

B/a

UNIVERSITY OF MIAMI

COLLEGE OF ARTS AND SCIENCES

Office of the Dean

MEMORANDUM

To: Steven Green, Chair, Faculty Senate

From: Kumble R. Subbaswamy, Dean
College of Arts and Sciences

Re: Proposal to Split Department of Mathematics and Computer Science

Date: January 25, 2000

On behalf of the Faculty of the College of Arts and Sciences I am very pleased to submit the enclosed proposal for the splitting of the currently existing Department of Mathematics and Computer Science into two separate departments within the College. The resulting two departments are to be named, respectively, the Department of Mathematics, and the Department of Computer Science. Along with the higher profile that computer science receives as a result, the College plans to increase support for strengthening computer science at the University of Miami. The College faculty has unanimously voted in favor of the proposal, and the Provost has indicated his strong support. We now ask the Senate for its approval. Thank you for your prompt attention to this important matter.

KRS/zr
Enclosures

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A Proposal for Splitting the
Department of Mathematics and Computer Science
Into Two Separate Departments
within the
College of Arts and Sciences
at the
University of Miami

Introduction.

At its meeting of November 15, 1999, the faculty of the College of Arts and Sciences voted unanimously to approve the separation of the Department of Mathematics and Computer Science into two distinct departments: A Department of Mathematics and a Department of Computer Science. The College has offered the B.S. and M.S. degrees in computer science for more than 30 years through the Department of Mathematics and Computer Science. While the faculty of the mathematics department have nurtured and supported the growth of computer science within the College, the external environment and the needs of each discipline are such that future growth will be facilitated by this separation. An understanding has been reached between mathematics and computer science as to the division or sharing of existing courses, faculty, space and equipment. Additional faculty lines and technical and staff support have been committed to computer science to prevent any potential negative impact for mathematics.

External Environment

Why Computer Science?

Within the past quarter century, Computer Science has taken its place beside sciences up to one hundred times as old: Biology, the science of life; Chemistry, the science of atoms and molecules; Geology, the science of the Earth; Psychology, the science of mind; Physics, the science of what is; and Mathematics, the science of what could be. Computer Science joins this group as the science of computation. It is young because computers are young, but for the past half century, these computers have doubled their capabilities, without fail, every 18 months (Moore's Law), and may continue this exponential improvement well into the future.

Even if Computer Science were merely an ordinary new science, the University of Miami would have the duty to create and to support strong programs of research and teaching in it, as it would for any new field. However, Computer Science is far from ordinary. Computing enables other sciences more than any other field except, perhaps, mathematics. What science does not use computers? Furthermore, Computer Science spans a spectrum from abstract to applied almost as great as all other science combined, and unlike any other science. And thanks to Moore's law, Computer Science is ever changing. A computer program is almost as abstract as a mathematical theorem, yet almost as practically significant as a new biological life form, and if it runs too slowly now, just wait a year. What would Mathematics be like if theorems were worth millions of dollars? What would Biology be like if undergraduates could create new forms of life? What would Physics be like if the speed of light doubled every year and a half? That is what Computer Science is like.

Most comparable universities have an independent department of computer science (please see Appendix I). Those with an Engineering school also have Computer Engineering programs. Nationwide, the enrollment of undergraduate computer science majors exceeds that of computer engineering by more than a factor of three. Undergraduate enrollments in Computer Science in the U.S. doubled in 1996-8, and just about every university is expanding its Computer Science program. At the same time, industry is hiring away students even before they finish their Ph.Ds and luring away even senior faculty (see enclosed article from the Chronicle of Higher Education).

Internal Environment

Why a new department?

Is forming a new department right now the best way for the University of Miami to support Computer Science? Superficially, the evidence appears to the contrary. As recently as 1994, the University of Miami had seven regular Computer Science faculty (the fewest of any comparable university, but only by a little). Now, there are only two remaining with a third on leave in industry (and subject to the siren call of obscenely high salaries and stock options). With only two faculty remaining, the University of Miami faces the prospect of losing Computer Science entirely and entering the new millennium without it. We have to do something now.

With the establishment of a separate department, the state of affairs in computer science becomes very public, and very visible. This not only will help in recruiting faculty and students, it will also raise the stakes. We cannot afford to fail in this endeavor. Only by setting the stakes this high can we ensure that we will not repeat the mistakes of the past. Only in this manner can Computer Science succeed and grow at the University of Miami right now at the beginning of the new millennium. Up to this point, the mathematics faculty has done its utmost to maintain computer science at UM. The university administration is now providing the strongest possible support, and the College of Arts and Sciences has given its unanimous endorsement. In approving this proposal the rest of the university will signal its support of a strong computer science program at UM.

Degree Programs; Curricula

The B.S. and M.S. degrees in Computer Science (CS) currently exist (see Bulletin masthead material attached). The goal is to achieve accreditation from the Computer Science Accreditation Board within five years. These degrees require students to take courses in computer science, computer engineering (CE), and in mathematics (in addition to general education and core courses for the B.S.). No changes are anticipated in the degree requirements at this time. The policies for sharing of courses between the CS and CE now in force will be continued.

Budget

Faculty lines

The new Computer Science department will start out with a commitment of eight tenured or tenure-track lines. Six of these have been in the existing budget of the Department of Mathematics and

Computer Science for a number of years, and will simply move over to the new department. At the present time, there are three computer science faculty in the department, two tenured Associate Professors (Dr. Milenkovic and Dr. Sarkar) and one tenure-track Assistant Professor (Burton Rosenberg, currently on leave of absence). Funding for the two new positions will come from additional funds committed by the Provost to the College as a part of the appointment of Dean Subbaswamy. Recruitment of new faculty to fill the vacant and new positions will occur over the next few years at nationally competitive salaries. Funding sources have been identified within the College to provide competitive salaries and adequate start-up costs (one-time) as necessary.

Operating Support

We are in the process of creating a new Senior Staff Associate position to provide staff support for Computer Science. The departments of Mathematics and Computer Sciences will continue to share technical computer support personnel, but the level of support will be increased by 1 FTE. The operating budget for the new department will be on par with the prevailing rate for other departments in the College. Again, funding has been identified to cover the one-time-only costs associated with the creation of the department. New funding needed for the on-going increases will come from allocations made to the College as a part of the appointment of Dean Subbaswamy.

Graduate Assistants

The six Teaching Assistantships traditionally assigned to Computer Science students will transfer to the new department and two additional assistantship will be provided. The College has a total of 250 TA-lines. Allocations are examined and readjusted periodically depending on demand, teaching needs, job market conditions, quality of graduate programs, etc. Thus, the overall numbers in the two departments are expected to change over a period of time along with those in all other programs.

Space

Until such time as additional space can be made available, the two departments will continue to share the space currently occupied by the joint department. The College expects to obtain additional space when communication vacates its space in Merrick. To the extent possible, we will try to obtain space in the Ungar Building, to accommodate the anticipated need for new space for faculty offices and laboratory/research facilities.

Library Holdings

Since the B.S., and M.S. degrees in Computer Science have existed for a couple of decades, library holdings at UM in Computer Science are comparable to those in other established programs.

Revenue Implications

The College believes that a vibrant Department of Computer Science will produce sufficient incremental tuition and research-related revenue to more than justify the new funds committed above. As the rebuilding of faculty and facilities occurs, the College is committed to an agressive recruitment stragety to increase the number of (high quality) undergraduate computer science majors by 50 over the next five years. With a full-complement of faculty in place, we also anticipate a substantial increase in external funding and an expanded, tuition generating master's program.

Conclusion

Just a first step.

Finally, it must be recognized that even with eight faculty members, the new department will be the smallest Department of Computer Science among Group I research universities. This department is only the first step towards where the University of Miami should be in this computer age, and its establishment will proclaim to the world that we are committed to joining other Group I universities as a major player in the vital area of Computer Science in the years to come.

Computer Science [illegible]			
Name of College/University	**# of Faculty**	**# of Undergraduate Majors**	**# of Graduate Students**
Boston University/Computer Science Dept.	16*	Not Listed**	25
Brown University/Computer Science Dept.	22*	??574***	85
Duke University/Computer Science Dept.	35*	196	71
Florida International University/School of Computer Science	24*	Not Listed**	Not Listed**
John Hopkins University/Computer Science Dept.	39*	Not Listed**	62
University of Southern California/Computer Science Dept.	82*	Not Listed**	Not Listed**
Vanderbilt University/Computer Science Dept.	13*	70	Not Listed**
Washington University/Computer Science Dept.	33*	Not Listed**	101

*Includes: Professors, Assoc. Professors, Adjoint Professors, Adjunct Professors, Assistant Professors and Lecturers

** University Has An On-line Directory To Search For Individual Students By Name

***Counted Based On The Number Of Undergraduate Computer Science Students Having A Web-Site With The Computer Science Department

Relying solely on journal articles to evaluate computer-science professors for promotion and tenure is a mistake.

So says a statement released this month by the Computing Research Association, based in Washington. It urges academe to place as much weight on papers written for conferences—and on the "artifacts," such as software, created by professors—as on published articles.

"Relying on journal publications as the sole demonstration of scholarly achievement, especially counting such publications to determine whether they exceed a prescribed threshold, ignores significant evidence of accomplishment in computer science and engineering," says the statement, called "Best Practices Memo: Evaluating Computer Scientists and Engineers for Promotion and Tenure."

Among the top computer-science departments, the shift away from a sole reliance on journal articles has already happened, says David A. Patterson, a professor of computer science at the University of California at Berkeley. He helped draft the statement, and says it is intended to pass on the "best practices" to computer-science and engineering departments at a time when both the number and size of such programs are growing.

■

Professors in computer science and engineering are generally divided into two types: those who do theoretical research and those who do experimental research.

The theorists are more easily evaluated by academe's traditional emphasis on journal articles than are the experimentalists, the association's statement says, adding: "For experimentalists conference publication is preferred to journal publication, and the premier conferences are generally more selective than the premier journals."

Anecdotal evidence suggests that experimentalists are not getting promoted on campuses where tenure committees or administrators place too much emphasis on a scholar's published articles, says Lawrence Snyder, a professor of computer science and engineering at the University of Washington and one of the authors of the statement.

Says Mr. Patterson: "Our conferences, unlike many other fields, are refereed, have a very low acceptance rate, and involve relatively long papers. Given that our field has taken this approach to publication, for our people to be accepted in academe, we need to give visibility to these practices."

Hence the statement. It was crafted by Mr. Patterson, Mr. Snyder, and Stanford University's Jeffrey D. Ullman, and was approved by the association in August.

The statement has been published in the September issue of *Computing Research News*, and can be found on the World-Wide Web (http://www.cra.org/reports/tenure review.html).

Computer Scientists Flee Academe for Industry's Greener Pastures

Universities face severe faculty shortages at a time of booming undergraduate enrollments

BY ROBIN WILSON

JUST AS HE PREPARED to leave Cornell University last spring to help start a new high-technology company, Thorsten von Eicken got word that the computer-science department at Cornell had voted to grant him tenure.

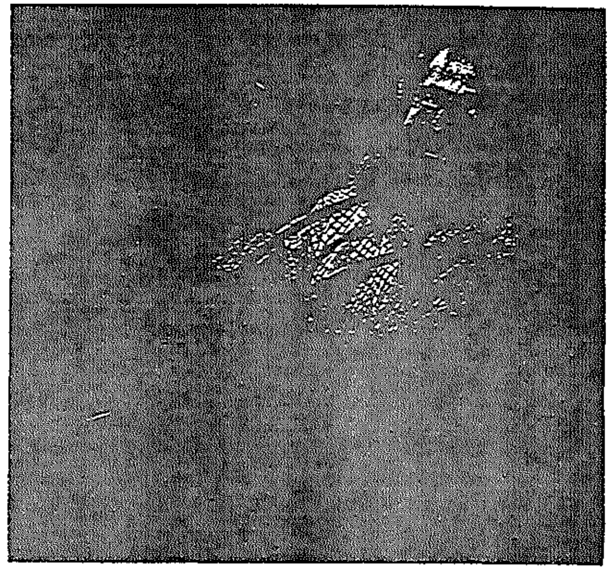
He left anyway.

Mr. von Eicken is part of a stampede of bright, young Ph.D.'s in computer science who are abandoning academe for the corporate world.

High-paying, fast-paced jobs in the computer industry are attracting both seasoned academics and newly minted Ph.D.'s who, in the past, would have opted for careers in higher education. The upshot: Computer-science and computer-engineering departments are suffering a serious shortage of professors at a time when undergraduate enrollments are booming.

Many departments are losing professors faster than they can hire them. The University of Illinois at Urbana-Champaign recruited five new professors in electrical and computer engineering to start this fall, but lost five others who were already on its faculty. The University of Washington recruited four scholars to its department of computer science and engineering but lost five. Cornell hired three but lost six. Among the departed was Mr. von Eicken, who moved to Santa Barbara, Cal., to help start Expertcity.com, which offers on-line technical advice on how to operate computers.

Mr. von Eicken is on a two-year leave from Cornell, but he is not keen on returning: "It is not obvious that academic research has the most impact."



Thorsten von Eicken, who left Cornell U. for a start-up company, says his new post is less stressful than the old: "The academic job is too many jobs all in one."

UNFILLED OPENINGS

Other scholars apparently feel the same way, and even top-ranked institutions such as Carnegie Mellon and Princeton Universities have faculty openings they can't fill. Some universities are extending twice as many job offers as they have openings, knowing that they will be lucky to lure even half of the candidates.

"The feeling in most computer-science departments is that we have an infinite number of openings," says David Dobkin, the chairman at Princeton, which made four offers last academic year but drew only one taker. This year, the university was more successful: It made four offers and hired three professors.

The situation at some lower-tier institutions is even bleaker. Saginaw Valley State University has been trying to hire a faculty member in computer science for two years, but has received only a handful of applications. In 1997, only five people applied. When the university tried to interview the two candidates whom it deemed suitable, it found they had already taken jobs elsewhere. Last year, the department received three applications, but two were from foreign professors whom the department could not afford to bring in for interviews. The third was from a candidate who had not yet finished his dissertation.

A surplus of faculty openings may sound like an enviable problem to scholars in other parts of academe, particularly in the humanities, where many Ph.D.'s have been unable to land tenure-track positions. But a report released this summer by the Washington-based Computing Research Association called the faculty shortage in computer science "severe." It said competition for Ph.D.'s from the private sector may pose a significant threat to the health of university departments.

"Some people are concerned about a seed-corn problem: that the high industrial demand for I.T. workers is siphoning off too many graduate students and faculty from the universities, leaving an insufficient number to educate the next generation of I.T. workers," said the report, called "The Supply of Information Technology Workers in the United States." All but 39 of the association's 187 members are Ph.D.-granting departments of computer science and computer engineering.

As a barometer of the demand for computer scientists, the association has seen revenue from employment advertisements in its bimonthly newsletter more than double in the last two years. The January 1999 issue of the newsletter, *Computing Research News*, carried employment ads from 91 colleges and universities, many of which listed multiple faculty openings. Last year, the January issue carried ads from 65 institutions.

DEMAND AND SUPPLY

The flight of computer scientists could not come at a worse time for universities, given two trends now colliding in academe: a surge in undergraduate enrollment in computer-science courses and an inadequate supply of Ph.D.'s in the field.

Student demand for information-technology courses and majors has led universities to try to bulk up on faculty members to handle the teaching load. Since 1995, undergraduate enrollment in such courses has doubled nationwide.

At Ohio State University, the number of computer-science majors has climbed from 850 to 1,300 in the last four years, and professors in computer and information science are teaching about 35 per cent more credit hours than they did in the past.

The university's computer-science department tried to hire seven new professors for the current academic year to deal with the student demand, but it attracted

Stuart H. Zweben, of Ohio State U.: "It has been somewhat of a war" to get graduate students to stay on.

TED RICE FOR THE CHRONICLE

Doug Burger, of the U. of Texas at Austin, says the dearth of graduate students is "a nightmare."

ROBERT BAUMGARDNER FOR THE CHRONICLE

only four. Meanwhile, the department lost two professors, one to another university and one to industry.

In recent years, so many students have been clamoring to major in computer science at the University of Washington that it has been able to accommodate only a quarter of them. Right now, the cap is set at 160 new majors a year. To keep up with demand, the university has been trying to expand the number of faculty members in its department of computer science and engineering from 29 to 34, but instead the roster has shrunk to 28. Now, with the state Legislature providing money to add new undergraduate programs in the field, including computer graphics and animation, the department figures it will need as many as 14 additional professors.

A DECLINE IN DOCTORATES

Complicating the hiring process, too many employers are chasing too few Ph.D.'s. The number of new Ph.D.'s in computer science and computer engineering peaked in 1992, at 1,113, and dropped to 933 by 1998, according to the Computing Research Association. Because of the booming job market in the computer industry, fewer people are enrolling in doctoral programs. And many of those who do enroll are jumping ship before their degrees are completed to accept job offers from corporations.

"It has been somewhat of a war trying to get students here and get them to stay here," says Stuart H. Zweben, chairman of computer and information science at Ohio State. "Students come and get a master's, and they feel that is enough of a ticket. They are reluctant to stay on for a Ph.D."

It is hard to persuade students to sweat out a doctoral education that lasts from five to seven years when people with only bachelor's and master's degrees are making boatloads of money in the computer industry. Two years ago, the University of Washington introduced a course in software entrepreneurship, only to see three Ph.D. students who had taken the course leave before finishing their degrees. They headed off to the business world to put their new skills to work.

Sometimes the pull comes even earlier. This month, a student who had signed up to enter the graduate program at Princeton contacted the university to say that the start-up company he works at is doing so well that he'd decided to stay put.

At the University of Texas at Austin, the number of people graduating with doctorates in computer science has fallen from 24 in 1991 to just 17 in 1998. As a result, some faculty members do not have enough graduate students to stock their own research groups, says Doug Burger, an assistant professor of computer science. "It's a nightmare," he says.

Elsewhere, research and teaching fellowships for graduate students either are going unused or are being given to students who intend to earn only a master's degree.

When doctoral students are hired by computer companies before they have fulfilled all of their academic responsibilities, faculty members are often left holding the bag. Bruce Hajek, a professor of electrical and computer engineering at the University of Illinois at Urbana-Champaign, says one of his star students got a job on Wall Street soon after completing his dissertation. The student—who during his last few weeks at Illinois could be heard fielding telephone calls from his new clients—left the university before he could submit journal articles on the ideas his dissertation had generated.

"We have contracts that fund the research, and we have to publish papers to get the money," says Mr. Hajek. "After he left, it took me two years to have time to go carefully through his thesis and abstract things and submit papers to a journal."

The only good news in all of this for universities is that when their students persevere and complete their Ph.D.'s, the job opportunities are bountiful. Every doctoral recipient can count on at least a half-dozen job offers, and many get more than that.

COMPETITION FROM INDUSTRY

By watching the career trajectories of their own Ph.D.'s, universities can easily see that their chief competition in the labor market comes from the computer industry. According to the Computing Research Association, 50 per cent of the new Ph.D.'s in computer science in 1996 took positions in industry. Only 26 per cent took faculty jobs. (The remainder secured postdoctoral positions or joined non-profit groups or other organizations.)

In the corporate world, new Ph.D.'s have a growing number of opportunities. Small start-up companies are popping up like dandelions. Established corporations, like Microsoft and Lucent Technologies, have founded basic-research groups in the last few years and have been stocking them with scholars. Microsoft's research group, founded in 1991, employs 400 people, the bulk of whom hold Ph.D.'s.

Henry F. Korth heads one of dozens of small research departments at Lucent Technologies that he says are "aggressively expanding." Mr. Korth himself left U.T.-Austin eight years ago to join the corporate world. "I did enjoy the academic life style," he says. "But where I am right now, I'm able to see the challenges of the real world and have the resources to do something about it."

He also stands to make much more money than he did in academe. For new Ph.D.'s in the field, starting salaries in higher education run about $65,000 to $70,000 for nine months' work. That's well above the average for new assistant professors in the humanities, but not nearly as attractive as starting salaries in industry, which are closer to $100,000 a year. More important are the stock options and other perks common in the high-tech sector.

According to Edward Lazowska, chairman of the University of Washington's computer-science-and-engineering department, people working in his state's software industry earn an average of $295,000 a year. That figure includes their paychecks and the value of exercised stock options.

"There ain't nothing going to happen at the University of Washington to cause people to start making $295,000 a year," he says. "There's nothing we can do to compete, so this had better be a fantastically fulfilling occupation, or people are going to start doing something else."

There's the rub. With more undergraduates to teach, fewer Ph.D. students to help on research and teaching, and an unstable cadre of colleagues with whom to share ideas, universities are hard-pressed to look attractive to job candidates.

"This fury of entrepreneurial activity is draining the very best talent" away from universities, says Kenneth P. Birman, a professor of computer science at Cornell. "It is cannibalizing many of the researchers who would have produced the next generation of major innovations."

The trouble is, he says, "if your work isn't exciting enough that industry is begging you to work with them, then you're probably not working on the right problem." But if your work is that exciting, you are probably headed out of academe.

For job candidates who are committed to staying in academe, so many universities are gunning for them that the stakes can get pretty high. To lure candidates, institutions offer to lighten the teaching load, pay a summer salary, and commit several graduate students to help with research. They also offer equipment and facilities that can push the value of a start-up package for a new computer-science professor to $500,000.

But for Thorsten von Eicken, perks like that weren't enough. He says it may be difficult to believe, but his new job at Expertcity.com is less stressful than his post at Cornell.

"The academic job is too many jobs all in one with too much responsibility," he says. "I had a research group to run with four or five graduate students, a number of undergraduates to worry about, while constantly being concerned about writing papers for publication. At the same time, I've got courses and I'm running after grants." At Expertcity.com, he says, "it's much simpler. What doesn't happen today will happen tomorrow."

One of Mr. von Eicken's colleagues at Cornell has also decided that life on the other side is brighter. Srinivasan Keshav left Cornell for good this summer to be chief technical officer of Ensim Corporation, a Silicon Valley company that assists Internet-service providers. He was expecting to earn tenure this academic year, one of his lifelong goals, but he decided it was worth sacrificing.

"It is like if you were a painter" during the Renaissance, Mr. Keshav says, "you had to be in Florence.

"If you are in computer science, in networking, you have to be out here in the Valley." ■

MATHEMATICS AND COMPUTER SCIENCE

Alan Zame *Chairman of the Department*

Cai, Cantrell, Chan, Chen, Connell *(emeritus)*, Coomes, Cosner, Duda, G. Galloway, M. Galloway, Goodman, Hertzig, Howard *(emeritus)*, Kaliman, Kelley, Koçak, Lazer, McDougle, Mielke, Milenkovic, Nunnally, Palmer, Pestien, Ramakrishnan, Rosenberg, Sarkar, Shareshian.

A. MATHEMATICS

The requirements of a **major** in mathematics vary according to the objectives of the student. The seven courses required of all mathematics majors are 111 or 131, 112 or 132, 210, 230, 310, 508 or 509 or 561, 533. An additional four courses are required, selected from one of the following options:

General Mathematics: four of 512, 531, 532, 534, 551, 562.

Applied Analysis: 311, 512, 513-514 or 515-516 (course work in physics is desirable).

Computational Mathematics: 320, 517, 520-521.

Probability and Statistics: 224, 524-525, 528 or 542.

Secondary School Teaching: 224, 502, 504-505 (only for those obtaining a teaching credential).

Mathematical Economics: MTH 524-525, ECO 512 or ECO 520 or ECO 521, ECO 533.

Students preparing for graduate study in mathematics should complete all of 531, 532, 533, 534, 561, 562.

Students interested in **actuarial science** should choose the Probability and Statistics option; for these students a finance minor is recommended.

Transfer students will be permitted to apply up to 14 transfer credits towards the major; however, the University of Miami's courses 508 (or 509 or 561) and 533 must be completed.

A **minor** in mathematics requires three of the following courses which must be taken in the Department of Mathematics and Computer Science, University of Miami: 210; 211 or 310 or 312; 224, 309, 311, 320; 500-level mathematics courses with departmental approval.

A grade of "C-" or better is required for each course applied toward the major or minor; the overall quality point average for the major or minor must be 2.5 or above.

Requirements for **departmental honors** in Mathematics: Three two-course sequences from 513-514, 515-516, 520-521, 524-525. 531-532. 533-534, 561-562; the student must attain at least a "B" in each course used to fulfill this requirement. In addition, the student must attain at least a 3.5 average overall all courses counted toward the mathematics major and an overall (university-wide) average of at least 3.3.

For requirements leading to the Master of Arts, Master of Science, Doctor of Arts, or Doctor of Philosophy degrees, with a major in mathematics, see the *Bulletin* of the Graduate School.

099. Intermediate Algebra
3 cr.
Real number operations, polynomials, factoring, rational numbers and rational expressions. *Prerequisite: Extreme deficiency in algebra. Cannot be used to fulfill the 120 credits required for graduation.*

101. Algebra for College Students
3 cr.
Algebraic operations and properties of the real numbers; linear and quadratic equations and inequalities; polynomials and factoring; rational expressions; radical expressions; graphs of lines; systems of linear equations. *Prerequisite: Adequate achievement on mathematics placement test. Not open to students with credit in MTH 105 or 107. Not for major or minor.*

103. Finite Mathematics
3 cr.
Statements, sets, partitions of sets, permutations, combinations probability, relations and functions, introduction to linear programming, matrices. *Prerequisite: MTH 101 or adequate achievement on Mathematics Placement Test. Not for major or minor.*

105. Algebra and Trigonometry
5 cr.
An intensive course in algebra and trigonometry as covered in MTH 107-108, but without analytic geometry. *Prerequisite: MTH 101 or adequate achievement on mathematics placement test. Not open to students with credit in MTH 107 or 108. Not for major or minor.*

107. Precalculus Mathematics I
3 cr.
Algebraic operations; equations and inequalities; complex numbers; functions and their graphs; polynomial, exponential, and logarithmic functions; systems of equations. *Prerequisite: Adequate achievement on mathematics placement test. Not open to students with credit in MTH 105. Not for major or minor.*

108. Precalculus Mathematics II
3 cr.
Rational functions; analytic geometry; trigonometric functions, identities, and equations. *Prerequisite: At least C- in MTH 107 or adequate achievement on mathematics placement test. Not open to students with credit in MTH 105. Not for major or minor.*

109. Introductory Calculus
3 cr.
A one semester survey of the fundamental principles of calculus: functions, limits, derivatives, definite integrals, applications. *Prerequisite: MTH 107 or adequate achievement on mathematics placement test. Not for major or minor. Not for B.S. students.*

110. Analytic Geometry and Calculus I
5 cr.
Introduction to plane analytic geometry, and the subject matter MTH 111. *Prerequisite: At least a C- in MTH 105 or adequate achievement on mathematics placement test and high school trigonometry. Not open to students with credit in MTH 111 or 131.*

111. Calculus I
4 cr.
Limits and continuity, derivatives and applications, the definite integral and applications. *Prerequisite: At least a C- in MTH 108 or adequate achievement on mathematics placement test together with completion of high school trigonometry and analytic geometry. Not open to students with credit in MTH 110 or 131.*

112. Calculus II
4 cr.
Transcendental functions, methods of integration, L'Hopital's Rule and improper integrals, infinite series, polar coordinates, and introduction to differential equations. *Prerequisite: MTH 110 or 111. Not open to students with credit in MTH 132.*

119. Computers and Society
3 cr.
Introduction to the practical use of computers, writing programs in the BASIC language, software packages. Not applicable to major or minor in Computer Science or Mathematics. For students interested in understanding and appreciating computers and their impact on society.

120. Computer Programming I
4 cr.
Introduction to object-oriented programming languages with emphasis on programming style and algorithm development. Lecture, 3 hours; laboratory, 2 hours. *Corequisite: MTH 108 or adequate score on the mathematics placement test.*

131. Calculus I
4 cr.
The theory of limits, the derivative and the definite integral, techniques and applications. The sequence MTH 131-132 is more conceptually oriented than MTH 111-112. *Prerequisite: At least a B in MTH 108 or adequate achievement on placement test and high school trigonometry and analytic geometry. Not open to students with credit in MTH 110 or 111.*

132. Calculus II
4 cr.
Continuation of MTH 131. Additional topics on the derivative and definite integral; improper integrals, infinite series, and introduction to differential equations. *Prerequisite: MTH 131. Not open to students with credit in MTH 112.*

210. Vectors and Matrices
3 cr.
Two and three dimensional vectors, inner products, vector products, matrix algebra, linear transformations, determinants, quadratic and bilinear forms. *Prerequisite or corequisite: MTH 112 or 132.*

211. Calculus III
3 cr.
Matrix algebra, vectors in space, partial differentiation, multiple integration. *Prerequisite: MTH 112. Not open to students with credit in MTH 312.*

220. Computer Programming II
3 cr.
Programming methodology using object-oriented programming languages. Linked lists, stacks, queues, binary trees, files, recursion, and elementary searching and sorting. *Prerequisite: MTH 120.*

224. Introduction to Probability and Statistics
3 cr.
Probability distributions, random variables, expectation and variance, point estimation, interval estimation, testing of hypothesis, analysis of variance. *Prerequisite: One semester of calculus.*

228. Assembly Language Programming
3 cr.
Number systems, data representation, instructions, addressing schemes, basic computer architecture, subroutines, macros, assembling and linking. *Prerequisite: MTH 120 or the equivalent.*

230. Introduction to Abstract Mathematics
3 cr.
Fundamentals of set theory, logic and methods of mathematical proof. *Prerequisite or corequisite: MTH 112 or 132.*

309. Discrete Mathematics I
3 cr.
Mathematical methods of Computer Science and Computer Engineering. Mathematical reasoning, sets, relations, functions, boolean algebra, combinatorics, graphs. *Prerequisite: MTH 111.*

310. Multivariable Calculus
3 cr.
Equations of curves, surfaces, solids; vector differential calculus; integration of scalar valued functions. Applications. *Prerequisite: MTH 210 and (112 or 132). Not open to students with credit in MTH 533.*

311. Ordinary Differential Equations
3 cr.
Linear differential equations, simultaneous equations, solutions in series, numerical solutions. *Prerequisite: MTH 112 or 132.*

312. Vector Analysis
3 cr.
Vector algebra, partial differentiation, multiple integration, scalar and vector fields, line and surface integrals. *Prerequisite: MTH 112. Not open to students with credit in MTH 211.*

317. Introduction to Data Structures
3 cr.
A second course in Pascal programming focusing on data abstractions; application and implementation of arrays, strings, stacks, queues, linked lists and trees. *Prerequisite: One semester of Pascal programming.*

320. Introduction to Numerical Analysis
3 cr.
Interpolation, quadrature, numerical solution of algebraic and transcendental equations, matrix inversion. *Prerequisite: MTH 210 or 211; knowledge of a structured programming language.*

322. C Programming and UNIX
3 cr.
Fundamentals of C programming in the UNIX environment; character and string manipulations, pointer arithmetic, functions, structures, system calls and shell programming. *Prerequisite: MTH 111, 120.*

350. Introduction to Digital Computer Systems
3 cr.
Logic and sequential circuits, representation of information, instruction sets, addressing modes, subroutines, system software, basic computer architecture, memory organization and management, operating system concepts. *Prerequisite: MTH 120.*

471, 472. Directed Readings
1-3 cr. each
Topics selected from algebra, geometry, analysis, topology. *Prerequisite: Permission of department chairman.*

502. History of Mathematics
3 cr.
The development of mathematics from its earliest beginnings through the first half of the twentieth century. Numeral systems, geometry, algebra, analysis and set theory. *Prerequisite: Two courses in mathematics at the 200 level or above.*

504. Foundations of Geometry
3 cr.
Axiom systems and models of Euclidean and Non-Euclidean geometry. *Prerequisite: MTH 230 or 309.*

505. Theory of Numbers
3 cr.
Divisibility, primes; congruences; quadratic residues and reciprocity; Diophantine equations. Applications to cryptography. *Prerequisite: MTH 210 or 504.*

506. Logic
3 cr.
Propositional and first-order logic: completeness. Computational logic: Robinson's resolution. Formalized theories: arithmetic, Gödel's incompleteness theorem, Tarski's theorem on undefinability of truth. *Prerequisite: MTH 230 or 309 or permission of the instructor.*

508. Survey of Modern Algebra
3 cr.
Algebraic systems, equivalence classes, groups, rings, fields, unique factorization domains. *Prerequisite: MTH 210 and 230. Not open to students with credit in MTH 509 or 561.*

509. Discrete Mathematics II
3 cr.
Groups and combinatorics; applications of group theory to computer design and error correcting codes; Semigroups and applications to finite state machines; rings and fields; applications of Boolean algebra to computer design. *Prerequisite: MTH 210, 309.*

512. Elementary Complex Analysis
3 cr.
Complex variables; conformal mapping, contour integration. *Prerequisite: MTH 211 or 310.*

513. Partial Differential Equations I
3 cr.
Derivation, well posedness, and qualitative properties of initial value and boundary value problems for the heat, wave and Laplace equations. Energy methods, causality, maximum principles, heat kernels, Fourier series, and potential theory. *Prerequisite: MTH 210, 311 and either MTH 310 or 312.*

514. Partial Differential Equations II
3 cr.
Continuation of MTH 513. Approximations of solutions, distributions and integral transform methods, spectral theory and scattering. Applications to physical problems. Nonlinear equations and phenomena. *Prerequisite: MTH 513 or permission of the instructor.*

515. Ordinary Differential Equations
3 cr.
Linear systems, equilibria and periodic solutions, stability analysis, bifurcation, phase plane analysis, boundary value problems, applications to engineering and physics. *Prerequisite: MTH 311 and either MTH 211 or 310.*

516. Dynamics and Bifurcations
3 cr.
Bifurcation of equilibria and periodic solutions, global theory of planar systems, planar maps, nonlinear vibrations, forced oscillations, chaotic solutions, Hamiltonian systems, applications to engineering and physics. *Prerequisite: MTH 515 or permission of the instructor.*

517. Data Structures and Algorithm Analysis
3 cr.
Data abstraction, formal specification, trees, B-trees, balanced binary trees, graphs, searching and sorting. Algorithm analysis. Memory management. *Prerequisite: MTH 112, 220, and 309.*

518. Interpreters and Compiler Theory
3 cr.
Translation of higher-level languages into machine language. Topics in computer translation theory include grammars, parsing, scanners, precedence relations, run-time storage and symbol table organization, semantic routines, chaining and hashing, code generation and optimization, and macro implementation. *Prerequisite: MTH 519.*

519. Programming Languages
3 cr.
Formal definition of programming languages including specification of syntax and semantics; simple statements; global properties of algorithmic languages including scope of declarations, storage allocations, grouping of statements, subroutines, coroutines, and tasks; run time representation of program and data structures. *Prerequisite: MTH 517.*

520. Numerical Analysis I
3 cr.
Numerical linear algebra including the algebraic eigenvalue problem. *Prerequisite: MTH 320 or permission of department chairman.*

521. Numerical Analysis II
3 cr.
Numerical solution of ordinary and partial differential equations. *Prerequisite: MTH 320 or 520 or permission of department chairman.*

523. Principles of Filing and Database Systems
3 cr.
Theory and design of database systems with emphasis given to relational techniques. Topics include relational algebra and calculus, filing structures, relational modeling, query languages, and optimization. *Prerequisite: MTH 517.*

524. Introduction to Probability Theory
3 cr.
Probability spaces, random variables, expectation, limit theorems. *Prerequisite: MTH 310 or permission of department chairman.*

525. Introduction to Mathematical Statistics
3 cr.
Probability distributions, theory of sampling and hypothesis testing. *Prerequisite: MTH 524.*

527. Theory of Automata
3 cr.
Finite-state automata, context-free grammars, pushdown automata, Turing machines and computability. *Prerequisite: MTH 309 or 508.*

528. Combinatorics
3 cr.
Permutations and combinations, generating functions, enumerative analysis. *Prerequisite: One of the following: MTH 508, 509 or 561.*

529. Introduction to Computer Graphics
3 cr.
Transformations, sequences, and geometry by graphical methods: representation, manipulation and display of geometric information, 2-D and 3-D representations, transformations and display techniques, display and input devices, software packages. *Prerequisite: MTH 517.*

531, 532. Topology
3 cr. each
Set algebra, cardinal and ordinal numbers, axiom of choice, topological spaces, compactness, connectedness, separation properties, quotient spaces, Tychonoff Theorem, compactification. *Prerequisite: Permission of department chairman.*

533. Introduction to Real Analysis I
3 cr.
Numerical sequences and series; continuity; differentiation; integration; sequences and series of functions; Fourier series; functions of several variables; implicit and inverse function theorems. *Prerequisite: MTH 211 (or 310) and 230.*

534. Introduction to Real Analysis II
3 cr.
Continuation of MTH 533. *Prerequisite: MTH 533.*

540. Algorithm Design and Analysis
3 cr.
Design techniques include divide-and-conquer, greedy method, dynamic programming, backtracking. Time and space complexity. Sorting, searching, combinatorial and graph algorithms. *Prerequisite: MTH 517.*

542. Statistical Analysis
3 cr.
Statistical inference about one or two populations from interval, ordinal and categorical data; analysis of variance; simple and multiple linear regression; designing research studies. *Prerequisite: MTH 224, 310 (or 211 or 312).*

544. Computer Modeling
3 cr.
Modeling and simulation landscape, statistical inference, languages, discrete simulation of computer systems, mathematical modeling, hardware trends and their impact in simulation. *Prerequisite: MTH 224 and 517.*

545. Introduction to Artificial Intelligence
3 cr.
Artificial Intelligence principles and methods; game theory, optimal strategies, logical reasoning, heuristic and adaptive programming; LISP and/or PROLOG. *Prerequisite: MTH 220 or 317.*

551. Introduction to Differential Geometry
3 cr.
Geometry of curves and surfaces in Euclidean space. Local space curve theory, intrinsic and extrinsic curvature of surfaces, geodesics, parallelism, and differential forms. *Prerequisite: MTH 210 and one of MTH 211, 310, 312, or permission of instructor.*

555. Multimedia Systems
3 cr.
Specification and requirements of a multimedia hardware system, analog video, digital audio and video fundamentals, graphics file formats, data compression, CD technology, software, and multimedia application development. *Prerequisite: MTH 517.*

561. Abstract Algebra
3 cr.
Groups; rings; linear algebra; modules. *Prerequisite: MTH 210 and permission of department chairman.*

562. Abstract Algebra
3 cr.
Continuation of MTH 561. *Prerequisite: MTH 561.*

591-594. Topics in Mathematics
1-3 cr. each

595-599. Topics in Computer Science
1-3 cr. each

B. COMPUTER SCIENCE

The requirements for the major in Computer Science consist of all of the courses from the COMPUTER SCIENCE list, all of the courses from the MATHEMATICS list, and one of the 3 credit-hour courses from the ELECTIVES list, below. These courses cover material recommended by the Association of Computing Machinery.

COMPUTER SCIENCE (28 Credits)

MTH 120. *Computer Programming I*
MTH 220. *Computer Programming II*
EEN 304. *Logic Design*
MTH 228. *Assembly Language Programming*
MTH 517. *Data Structures and Algorithm Analysis*
MTH 519. *Programming Languages*
MTH 523. *Principles of Filing and Database Systems*
EEN 414. *Computer Organization and Design*
EEN 521. *Computer Operating Systems*

MATHEMATICS (17 Credits)

MTH 111 or 131 *Calculus I*
MTH 112 or 132 *Calculus II*
MTH 210. *Vectors and Matrices*
MTH 224. *Introduction to Probability and Statistics*
MTH 309. *Discrete Mathematics I*

ELECTIVES

MTH 320. *Introduction to Numerical Analysis*
MTH 509. *Discrete Mathematics II*
MTH 518. *Interpreters and Compiler Theory*
MTH 520. *Numerical Analysis I*
MTH 521. *Numerical Analysis II*
MTH 524. *Introduction to Probability Theory*
MTH 525. *Introduction to Mathematical Statistics*
MTH 527. *Theory of Automata*
MTH 528. *Combinatorics*
MTH 529. *Introduction to Computer Graphics*
MTH 540. *Algorithm Design and Analysis*
MTH 544. *Computer Modeling*
MTH 545. *Introduction to Artificial Intelligence*
MTH 555. *Multimedia Systems*
MTH 596-599. *Topics in Computer Science* (with approval of the department chair)

EEN 4[illegible] *Embedded Microprocessor System Design*
EEN 511. *Software Engineering*
EEN 514. *Computer Architecture*
CIS 526. *COBOL Applications and Implementation*
EEN 532. *VLSI Systems*
EEN 542. *Digital Integrated Circuits*
EEN 554. *Advanced Digital Systems*
CIS 530. *CICS Programming*

Transfer students will be permitted to apply up to 15 transfer credits towards the major; however, the University of Miami's MTH 517, 519, and 523 must be completed.

A minor requires three of the following courses: MTH 220, 228, 320, 517, 519, or other 500-level computer science courses with department approval.

A grade of "C-" or better is required of each course applied towards the major or minor; the overall quality point average for the major or minor must be 2.5 or above.

Undergraduates in Computer Science receive access to the department's extensive computer system. Additional information is available on the Internet at `http://www.cs.miami.edu`.

C. Medical Informatics

This program leads to a B.S. degree in Computer Science, tailored to the needs of students who are planning to work in a medical environment after graduation—including pre-medical, pre-dental, and pre-nursing students. The Medical Informatics program consists of three parts: (1) the basics of hardware and software systems, (2) information storing, retrieving, processing, and analysis, and (3) the application of the knowledge acquired in parts (1) and (2) to a medical environment. The requirements for the major are: the following list of nine computer science courses (28 credits), all of the courses from the MATHEMATICS list in Section B (17 credits), and an internship in medical information systems at a hospital or medical center (3 credits). The Department will help students find an internship.

MTH 120. *Computer Programming I*
MTH 220. *Computer Programming II*
MTH 350. *Introduction to Digital Computer Systems*
MTH 517. *Data Structures and Algorithm Analysis*
MTH 519. *Programming Languages*
CIS 520. *Analysis of Information Systems*
MTH 523. *Principles of Filing and Database Systems*
MTH 542. *Statistical Analysis*
MTH 555. *Multimedia Systems*

Students in the Medical Informatics program will have enough flexibility to include all courses necessary for a pre-medical or pre-dental curriculum within a 120-credit-hour plan of study; students may wish to consult the University of Miami Premedical Guide.

D. Double Major in Computer Science and Mathematics

Students may obtain a double major in mathematics and computer science by either completing the following program of mathematics and computer science courses, or by satisfying the requirements of both majors as described in Sections A and B. In either case, no course may be counted towards both majors.

MATHEMATICS (all of the courses from the *Core* list, and one of the courses from the *Electives* list, below.)

Core: (29 credits): MTH 131 or (111), 132 or (112), 210, 224, 230, 309, 310, 320, 509.

Electives (3 credits): MTH 520, 521, 524, 525, 527, 528, 533, 542.

COMPUTER SCIENCE (all of the courses from the *Core* list, and one of the courses from the *Electives* list, below.)

Core (28 credits): MTH 120, 220, 228, 517, 519, 523; EEN 304, 414, 521.

Electives (3 credits): MTH 518, 520, 521, 527, 529, 540, 544, 545; 596-599 (with department chair's approval); EEN 324, 514.

E. Mathematics or Computer Science as a Second Major for Engineering Students

Students who are majors in the College of Engineering may obtain a second major in Mathematics upon satisfactory completion of at least 18 credits in mathematics courses, at the 300-level or above, in addition to the coursework required for the Engineering major. The final program must include the courses: MTH 210, 230; 508 or 509 or 561; 533, and twelve additional credits from one of the Mathematics options described in section A.

Students who are majoring in Computer Engineering may obtain a second major in Computer Science upon satisfactory completion of 15 credits chosen from the "COMPUTER SCIENCE" and "ELECTIVES" lists in Section B, in addition to the coursework required for the Computer Engineering major. The final program must include the courses: MTH 517, MTH 519 and 523, in one of the two majors.

MATHEMATICS AND COMPUTER SCIENCE

Alan Zame, *Chairman*
Robert L. Kelley, *Associate Chairman*
Marvin Mielke, *Director of Graduate Studies*

Eric D. Belsley *(probability, algebra)*;
Mingliang Cai *(differential geometry)*;
Robert S. Cantrell *(differential equations, non-linear analysis)*;
Timothy Chan *(Computational Geometry)*;
Robert Chen *(probability, statistics)*;
Brian Coomes *(differential equations, dynamical systems)*;
Chris Cosner *(partial differential equations)*;
Edwin Duda (general *topology)*;
Gregory J. Galloway *(differential geometry, relativity)*;
Michelle Galloway *(combinatorics, computer science)*;
Shulim Kaliman *(algebra, complex analysis)*;
Huseyin Kocak *(dynamical systems, computer graphics)*;
Alan C. Lazer *(differential equations)*;
Marvin Mielke *(algebraic topology)*;
Victor J. Milenkovic *(computational geometry, layout algorithms)*;
Kenneth Palmer *(differential equations)*;
Kevin Payne *(analysis)*;
Victor C. Pestien *(probability, optimization)*;
Subramanian Ramakrishnan *(probability, statistics)*;
Burton Rosenberg *(computational geometry, algorithms)*;
Dilip Sarkar *(computer science)*;
John Shareshian *(Algebra, combinatorics)*;
Alan Zame *(analysis, probability)*.

The Mathematics and Computer Science Department offers graduate degree programs leading to the Master of Arts, Master of Science, Doctor of Arts and Doctor of Philosophy degrees in Mathematics and Master of Science in Computer Science. Prerequisites and requirements for these degrees are described below:

MASTER OF ARTS IN MATHEMATICS

Prerequisite: A minimum of nine credits in mathematics courses numbered 200 and above is required.
Requirements:

1. A total of 30 credits must be earned. At least 18 credits in mathematics courses are needed. All courses from other departments must be numbered 600 or above and be pertinent to secondary teaching of mathematics.
2. A two-hour oral examination covering the material in MTH 504, 508 or 509 or 561, 524, 525, 531, and 533 must be passed. These courses will form a part of the student's program except where an equivalent course was passed at the undergraduate level.

MASTER OF SCIENCE IN MATHEMATICS

Prerequisite: A minimum of 15 credits in mathematics courses numbered 200 and above is required.
Requirements:

1. A total of 30, 33, or 36 credits in approved courses must be earned, depending on whether at least 15, 12-14, or 9-11 credits, respectively, are in mathematics courses numbered 600 and above. A minimum of 24 credits must be earned in mathematics courses. At least two of the basic sequences 531-532, 533-534, and 561-562 are required.
2. Three written exams, at least two of which are on the basic sequences of the above list, must be passed.

DOCTOR OF ARTS IN MATHEMATICS

The following requirements are in addition to the general requirements for the Doctor of Arts Degree as described by the Graduate School (see section on Doctor of Arts elsewhere in this *Bulletin*).

1. A minimum of 24 credits must be earned in mathematics courses numbered 600 and above, and at least three of the basic sequences, 630-631, 632-633, 640-641, and 661-662 or their equivalents are required.
2. Three written exams on the basic sequences must be passed.

DOCTOR OF PHILOSOPHY IN MATHEMATICS

The following requirements are in addition to the general requirements for the Doctor of Philosophy Degree as described by the Graduate School (see section on Doctor of Philosophy elsewhere in this *Bulletin*).

1. A minimum of 36 credits must be earned in mathematics courses numbered 600 and above. All four basic sequences 630-631, 632-633, 640-641, and 661-662 or their equivalents are required.
2. Four written exams must be passed. Three of these must be from the above basic sequences; the other may be from the fourth basic sequence or in the candidate's area of specialty.
3. A proficiency in one of the languages French, German, or Russian must be demonstrated.

MASTER OF SCIENCE IN COMPUTER SCIENCE

Prerequisite:

A minimum of 15 credits in computer science courses numbered 200 and above is required. Students may be admitted with deficiencies; these must be completed in addition to the degree requirements.

Requirements:

A total of 30, 33, or 36 credits in approved courses, depending on whether at least 15, 12-14, or 9-11 credits, respectively, are in computer science courses numbered 600 or above. Students must either

1. choose the thesis option for a total of six thesis credits; these credits are included in the 30-36 credit requirement, or
2. take additional courses, if necessary, to increase the number of credits in approved courses to 36.

At least 15 credits, exclusive of the thesis credits, must be earned in the courses offered by the Department of Mathematics and Computer Science.

Each program must include both theoretical and experimental topics. Recommended subjects include Operating Systems, Programming Languages, Analysis of Algorithms, Theory of Computation, Graphics, Computational Geometry, Computer Architecture, Multimedia Systems, or Software Development. The approval is made by the Computer Science Committee and the Department Chairman or designate. Programs may thus be individually tailored to meet varied backgrounds and objectives. It is recognized that there are still individuals with undergraduate degrees in other fields wishing to pursue graduate work in Computer Science, and other individuals with work experience in the field wishing to advance their formal training in Computer Science.

The Graduate Computer Science Course Summary lists courses which may be considered for approval in completing the requirements for a degree. The basic guidelines for approval of a student's program are recommendations appearing in the Communications of the Association for Computing Machinery (ACM), the professional society in Computer Science. The courses in the Summary are generally grouped according to categories used in the ACM Journal.

Graduate students in Computer Science receive on-site access to the department's computers—including five VAX workstations and three Unix machines, and 15 SGI Indy Workstations—PLUS remote access to others via the on-campus network. Additional information is available on the Internet at `http://www.cs.miami.edu`.

GRADUATE COMPUTER SCIENCE COURSE SUMMARY
(* M.S. *)

ARTIFICIAL INTELLIGENCE

MTH 545. *Introduction to Artificial Intelligence*
MTH 645. *Introduction to Expert Systems*
MTH 646. *Neural Computing*
EEN 653. *Pattern Recognition and Neural Networks*

CIRCUIT DESIGN

EEN 542. *Digital Integrated Circuits*

COMBINATORICS AND GRAPH THEORY

MTH 528. *Combinatorics*

COMPUTER ARCHITECTURE

EEN 514. *Computer Architecture*
EEN 614. *Advanced Computer Architecture*
EEN 650. *Fault-Tolerant Computer Design*

COMPUTER GRAPHICS AND COMPUTATIONAL GEOMETRY
MTH 529. *Introduction to Computer Graphics*
EEN 638. *Computer Vision*
MTH 647. *Computational Geometry*

COMPUTER SYSTEMS
MTH 609. *Cryptography and Data Security*
EEN 532. *VLSI Systems*
CIS 528. *System Software Concepts*
EEN 534. *Computer Communication Networks*
EEN 634. *Modeling and Analysis of Computer Networks*
CIS 631. *Computer and Communication Security*
EEN 656. *Information Theory*

DATABASE THEORY
MTH 523. *Principles of Filing and Database Systems*
MTH 623. *Theory of Relational Databases*
EEN 621. *Object-Oriented Database Systems*

DATA STRUCTURES AND ALGORITHMS
MTH 517. *Data Structures and Algorithm Analysis*
MTH 628. *Parallel Algorithms*
MTH 540. *Algorithm Design and Analysis*

FORMAL LANGUAGES AND AUTOMATA
MTH 527. *Theory of Automata*

MULTIMEDIA
MTH 555. *Multimedia Systems*
MTH 655. *Advanced Multimedia Systems*

NUMERICAL ANALYSIS
MTH 520. *Numerical Analysis I*
MTH 521. *Numerical Analysis II*
MAS 647. *Linear Programming and Extensions*

OPERATING SYSTEMS
EEN 521. *Computer Operating Systems*

PROBABILITY AND STATISTICS
MTH 524. *Introduction to Probability Theory*
MTH 525. *Introduction to Mathematical Statistics*

PROGRAMMING LANGUAGES AND SYSTEMS
MTH 518. *Interpreters and Compiler Theory*
MTH 519. *Programming Languages*
CIS 526. *COBOL Applications and Implementation*
CIS 530. *CICS Programming*

SYMBOLIC ALGEBRA
MTH 509. *Discrete Mathematics II*

SYSTEM MODELING, ANALYSIS AND SIMULATION
MTH 544. *Computer Modeling*
MTH 613. *Computer System Performance Evaluation*
MTH 644. *Advanced Computer Modeling*

THEORY OF COMPUTATION AND COMPLEXITY
MTH 611. *Theory of Computation*
MTH 612. *Complexity Theory*

MASTER'S THESIS
MTH 710. One to six credits per semester, for a total of 6 credits.

G502. History of Mathematics
3 cr.
The development of mathematics from its earliest beginnings through the first half of the twentieth century. Numeral systems, geometry, algebra, analysis and set theory. *Prerequisite: Two courses in mathematics at the 200 level or above.*

G504. Foundations of Geometry
3 cr.
Axiom systems and models of Euclidean and Non-Euclidean geometry. *Prerequisite: MTH 230 or 309.*

G505. Theory of Numbers
3 cr.
Divisibility, primes; congruences, quadratic residues and reciprocity; Diophantine equations. Applications to cryptography. *Prerequisite: MTH 210 or 504.*

G506. Logic
3 cr.
Propositional and first-order logic: completeness. Computational logic: Robinson's resolution. Formalized theories: arithmetic, Gödel's incompleteness theorem, Tarski's theorem on undefinability of truth. *Prerequisite: MTH 230 or 309 or permission of the instructor.*

G508. Survey of Modern Algebra
3 cr.
Algebraic systems, equivalence classes, groups, rings, fields, unique factorization domains. *Prerequisite: MTH 210 and 230. Not open to students with credit in MTH 509 or 561.*

G509. Discrete Mathematics II
3 cr.
Groups and combinatorics; applications of group theory to computer design and error correcting codes; Semigroups and applications to finite state machines; rings and fields; applications of Boolean algebra to computer design. *Prerequisite: MTH 210, 309.*

G512. Elementary Complex Analysis
3 cr.
Complex variables; conformal mapping, contour integration. *Prerequisite: MTH 211 or 310.*

G513. Partial Differential Equations I
3 cr.
Derivation, well posedness, and qualitative properties of initial value and boundary value problems for the heat, wave, and Laplace equations. Energy methods, causality, maximum principles, heat kernels, Fourier series, and potential theory. *Prerequisite: MTH 210, 311 and either MTH 310 or 312.*

G514. Partial Differential Equations II
3 cr.
Continuation of MTH 513. Approximations of solutions, distributions and integral transform methods, spectral theory and scattering. Applications to physical problems. Nonlinear equations and phenomena. *Prerequisite: MTH 513 or permission of the instructor.*

G515. Ordinary Differential Equations
3 cr.
Linear systems, equilibria and periodic solutions, stability analysis, bifurcation, phase plane analysis, boundary value problems, applications to engineering and physics. *Prerequisite: MTH 311 and either MTH 211 or 310.*

G516. Dynamics and Bifurcations
3 cr.
Bifurcation of equilibria and periodic solutions, global theory of planar systems, planar maps, nonlinear vibrations, forced oscillations, chaotic solutions, Hamiltonian systems, applications to engineering and physics. *Prerequisite: MTH 515 or permission of the instructor.*

G517. Data Structures and Algorithm Analysis
3 cr.
Data abstraction, formal specification, trees, B-trees, balanced binary trees, graphs, searching and sorting. Algorithm analysis. Memory management. *Prerequisite: MTH 112, 220, and 309.*

G518. Interpreters and Compiler Theory
3 cr.
Translation of higher-level languages into machine language. Topics in computer translation theory include grammars, parsing, scanners, precedence relations, run-time storage and symbol table organization, semantic routines, chaining and hashing, code generation and optimization, and macro implementation. *Prerequisite: MTH 519.*

G519. Programming Languages
3 cr.
Formal definition of programming languages including specification of syntax and semantics; simple statements; global properties of algorithmic languages including scope of declarations, storage allocations, grouping of statements, subroutines, coroutines, and tasks; run time representations of program and data structures. *Prerequisite: MTH 517.*

G520. Numerical Analysis I
3 cr.
Numerical linear algebra including the algebraic eigenvalue problem. *Prerequisite: MTH 320 or permission of department chairman.*

G521. Numerical Analysis II
3 cr.
Numerical solution of ordinary and partial differential equations. *Prerequisite: MTH 320 or 520 or permission of department chairman.*

G523. Principles of Filing and Database Systems
3 cr.
Theory and design of database systems with emphasis given to relational techniques. Topics include relational algebra and calculus, filing structures, relational modeling, query languages, and optimization. *Prerequisite: MTH 517.*

G524. Introduction to Probability Theory
3 cr.
Probability spaces random variables, expectation, limit theorems. *Prerequisite: MTH 310 or permission of department chairman.*

G525. Introduction to Mathematical Statistics
3 cr.
Probability distributions, theory of sampling and hypothesis testing. *Prerequisite: MTH 524.*

G527. Theory of Automata
3 cr.
Finite-state automata, context-free grammars, pushdown automata, Turing machines and computability. *Prerequisite: MTH 309 or 508.*

G528. Combinatorics
3 cr.
Permutations and combinations, generating functions, enumerative analysis. *Prerequisite: One of the following: MTH 508, 509 or 561.*

G529. Introduction to Computer Graphics
3 cr.
Transformations, sequences, and geometry by graphical methods: representation, manipulation and display of geometric information, 2-D and 3-D representations, transformations and display techniques, display and input devices, software packages. *Prerequisite: MTH 517.*

G531, 532. Topology
3 cr. each
Set algebra, cardinal and ordinal numbers, axiom of choice, topological spaces, compactness, connectedness, separation properties, quotient spaces, Tychonoff Theorem, compactification. *Prerequisite: Permission of department chairman.*

G533. Introduction to Real Analysis I
3 cr.
Numerical sequences and series; continuity; differentiation; integration; sequences and series of functions; Fourier series; functions of several variables; implicit and inverse function theorems. *Prerequisite: MTH 211 (or 310) and 230.*

G534. Introduction to Real Analysis II
3 cr.
Continuation of MTH 533. *Prerequisite: MTH 533.*

G540. Algorithm Design and Analysis
3 cr.
Design techniques include divide-and-conquer, greedy method, dynamic programming, backtracking. Time and space complexity. Sorting, searching, combinatorial and graph algorithms. *Prerequisite: MTH 517.*

G542. Statistical Analysis
3 cr.
Statistical inference about one or two populations from interval, ordinal and categorical data; analysis of variance; simple and multiple linear regression; designing research studies. *Prerequisite: MTH 224, 310 (or 211 or 312).*

G544. Computer Modeling
3 cr.
Modeling and simulation landscape, statistical inference, languages, discrete simulation of computer systems, mathematical modeling, hardware trends and their impact in simulation. *Prerequisite: MTH 224 and 517.*

G545. Introduction to Artificial Intelligence
3 cr.
Artificial Intelligence principles and methods; game theory, optimal strategies, logical reasoning, heuristic and adaptive programming; LISP and/or PROLOG. *Prerequisite: MTH 220 or 317.*

G551. Introduction to Differential Geometry
3 cr.
Geometry of curves and surfaces in Euclidean space. Local space curve theory, intrinsic and extrinsic curvature of surfaces, geodesics, parallelism, and differential forms. *Prerequisite: MTH 210 and one of MTH 211, 310, 312, or permission of instructor.*

G555. Multimedia Systems
3 cr.
Specification and requirements of a multimedia hardware system, analog video, digital audio and video fundamentals, graphics file formats, data compression, CD technology, software, and multimedia application development. *Prerequisite: MTH 517.*

G561. Abstract Algebra
3 cr.
Groups: rings; linear algebra; modules. *Prerequisite: MTH 210 and permission of department chairman.*

G562. Abstract Algebra
3 cr.
Continuation of MTH 561. *Prerequisite: MTH 561.*

G591-594. Topics in Mathematics
1-3 cr. each

G595-599. Topics in Computer Science
1-3 cr. each

606. Logic Programming
3 cr.
Programming in Prolog, fix-point semantics, declarative semantics, completeness of SLD-resolution, negation, implementation of logic programming languages, deductive databases. *Prerequisite: MTH 506 and a course in programming and data structures, or permission of the instructor.*

609. Cryptography and Data Security
3 cr.
Encryption algorithms; cryptographic techniques; access, information flow and inference controls. *Prerequisite: MTH 509.*

611. Theory of Computation
3 cr.
Recursive functions, Markov algorithms, Turing machines. Unsolvability. *Prerequisite: MTH 509 and at least one programming course.*

612. Complexity Theory
3 cr.
Models of computations, Blum's axioms, intractability, NP-completeness. *Prerequisite: MTH 611.*

613. Computer System Performance Evaluation
3 cr.
Queueing models of computer systems. Inputs and outputs. Models with job classes. Flow equivalence and hierarchical modelling. Memory, disk I/O, processors. *Prerequisite: MTH 544.*

621. Mathematical Probability
3 cr.
Development of the measure-theoretic approach to probability. Random variables, central limit theory, laws of large numbers, martingales. *Prerequisite: Permission of department chairman.*

623. Theory of Relational Databases
3 cr.
Relational operators, dependencies, covers for functional dependencies, and normal forms. Representation theory, query systems, acyclic database schemes. *Prerequisite: MTH 523.*

625. Multivariate Analysis
3 cr.
Sampling theory for multivariate normal populations. Component and factor analysis. Stochastic difference equations. *Prerequisite: MTH 525.*

628. Parallel Algorithms
3 cr.
Parallel computation models; sorting networks; parallel algorithms for sorting, searching, graph problems, prefix computation, pattern matching, and fast Fourier transforms; theory of P-completeness, the class NC. *Prerequisite: MTH 540.*

630, 631. Real Variables
3 cr. each
Lebesgue measure and the Lebesgue Integral for R^1, Banach Spaces. General measure theory. topological groups and Haar Measure. *Prerequisite: MTH 532.*

632, 633. Complex Variables
3 cr. each
Complex numbers line or transformations, analytic function, conformality. Cauchy's Theorem, representation theorems, harmonic functions. *Prerequisite: MTH 531.*

638. Stochastic Processes
3 cr.
Prerequisite: MTH 631.

640, 641. Algebraic Topology
3 cr. each
Homotopy, covering space, Eilenberg-Steenrod axioms for (co) homology theories, Mayer-Vietoris sequences, Universal Coefficient theorem, Kunneth formula, computations and applications. *Prerequisite: MTH 532.*

644. Advanced Computer Modeling
3 cr.
Formal theories and axiomatic approaches. Process, interactive and robot-oriented simulation. Large systems and computer networks. Emulation and dynamic system evaluation. Modeling using Fuzzy concepts. Simulation and expert systems. *Prerequisite: MTH 544.*

645. Introduction to Expert Systems
3 cr.
Overview of expert systems, architecture of expert systems, knowledge base and representation, inference engine, expert system tools, reasoning under uncertainty, explaining the reasoning, evaluation of expert systems. *Prerequisite: MTH 545.*

646. Neural Computing
3 cr.
Fundamentals of artificial neural networks; perceptrons, backpropagation, algorithm, pattern recognition; counterpropagation networks, data compression; Hopfield networks, optimization; bidirectional associatative memories; adaptive resonance theory. *Prerequisite: MTH 517 or equivalent.*

647. Computational Geometry
3 cr.
Algorithms for solving geometric problems arising from application domains including graphics, robotics, and GIS. *Prerequisite: MTH 517 or permission of instructor.*

651, 652. Differential Geometry
3 cr. each

655. Advanced Multimedia Systems
3 cr.
Digital-system fundamentals; digital audio, analog and digital video; graphics; data compression algorithms; CD-ROM technology; implementation of multimedia software development tools; architecture and issues for distributed multimedia systems; multimedia communications systems. *Prerequisite: MTH 555.*

657. Lie Groups
3 cr.

661, 662. Abstract Algebra
3 cr. each
Prerequisite: MTH 562.

670. Directed Readings of Research
2-4 cr.

680, 681. Topics in Analysis
3 cr. each

682, 683. Topics in Topology
3 cr. each

685. Topics in Algebra
3 cr.

686, 687. Topics in Mathematics
3 cr. each

688, 689. Topics in Computer Science
3 cr. each

690. Seminar for Beginning Graduate Students
1-3 cr.
The selection of topics will be flexible but will be of interest to beginning graduate students.

692. Seminar
1-2 cr.

710. Master's Thesis
1-6 cr.
The student working on his/her master's thesis enrolls for the number of credits as determined by his/her advisor. Credit is not awarded until the thesis has been accepted.

725. Continuous Registration-Master's Study
0 cr.
To establish residence for non-thesis master's students who are preparing for major examinations. Credit not granted. Regarded as full time residence.

730. Doctoral Dissertation
1-12 cr.
Required of all candidates for the Ph.D. The student will enroll for credit as determined by his/her advisor, but for not less than a total of 12 hours. Up to 12 hours may be taken in a regular semester, but not more than six in a summer session.

740. Research Project
1-6 cr.
Required of all candidates for the Doctor of Arts degree. Student enrolls for credit as determined by advisor. Credit is not awarded until the doctoral project has been accepted. Total enrollment may not exceed six credits.

750. Research in Residence
0 cr.
Used to establish research in residence for the Ph.D. and D.A., after the student has been enrolled for the permissible cumulative total in appropriate doctoral research. Credit not granted. May be regarded as full-time residence as determined by the Dean of the Graduate School.