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THE EDUCATIONAL PROGRAM IN NUMERICAL ANALYSIS
OF THE DEPARTMENT OF MATHEMATICS, U. C. L. A.

by

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A Technical Report

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Department of Mathematics
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The Educational Program in Numerical Analysis
of the Department of Mathematics, U.C.L.A.

by George E. Forsythe*

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University of California, Los Angeles

Numerical Analysis Research is a part of the Mathematics Department of the University of California, Los Angeles (U.C.L.A.). Operating under several contracts with the federal government, we have taken over the important research functions of the Institute for Numerical Analysis of the National Bureau of Standards, which was inactivated in June 1954. We operate SWAC, an electronic digital computer built by the National Bureau of Standards and loaned to us by the Department of Defense.

Our purpose is to carry out, expound, apply, and publish research in numerical analysis, including (a) pertinent fundamental research in mathematics; (b) research in the application of computers to scientific problems and related applications; and (c) supporting research in the engineering of electronic digital computers.

To carry out this work we have approximately five full time, reasonably permanent mathematicians; two to four (many more in summer) mathematicians as visitors or one-year appointees; about eight graduate student assistants (presently including one in physics and one in engineering); one digital computer supervisor; one professional coder; and a supporting administrative staff. Besides these, there are a variable number of students, assistants, and faculty members of other

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U.C.L.A. departments and of other universities who, while running their own problems, contribute materially to the life of our organization. Because of our shortage of computer staff, these "casuals" carry an increasing load of operating our facility.

As a city university, U.C.L.A. serves a most diverse student body. In mathematics we have undergraduates aiming at being teachers, and others who would be junior mathematicians in industry. We have graduate students seeking the master's or doctor's degree. There are a very large group of evening extension students, seeking self- or job-improvement. And, finally, Numerical Analysis Research is a center where industrial mathematicians exchange ideas at seminars. We have numerical activities for all these groups, and more.

There is a fair cleavage between two levels of numerical analysis education at U.C.L.A.: (1) work at the bachelor-master's level of maturity; (2) work at the pre-doctoral and post-doctoral level of maturity. I shall review our educational activities in two sections.

The work under (2) is an integral part of the purpose of Numerical Analysis Research, but that under (1) is not. We give advice about (1), and some of us teach undergraduate courses as visiting faculty members of the university.

1. Educational activities at the bachelor-master's level

The typical student who takes several of the undergraduate courses aims at being a computer or coder in an industrial organization in the Los Angeles area. The full-time regular undergraduate will get his bachelor's degree with the major in mathematics. (There is no recognized specialty in numerical analysis in any degree at U.C.L.A.) The extension student

who is already working hopes to become a computer or coder, or to better his position if he is already in the field. He may concentrate on taking the Certificate in Numerical Analysis mentioned below.

We regard specialization in the courses listed in this section as a terminal program, a little on the trade-school side. While a few students drop in who will later study for a doctor's degree in mathematics, we encourage these instead to take classical courses in analysis, algebra, and geometry. The material in our undergraduate courses in numerical analysis is probably not basic enough to be proper training for real mathematicians. On the other hand, a student doesn't always know his ability, his interests, and his future. Math. 139 or the informal coding course should give the uncertain student a good chance to learn his interests in digital computing, without detracting unduly from his basic mathematical training.

We are making an effort to develop syllabi and outlines of our undergraduate and graduate courses. These are now available for several of them.

Math. 135. Numerical Mathematical Analysis. A full year junior-senior course in general numerical analysis, taught from texts like Milne's "Numerical Calculus" and Hartree's "Numerical Analysis."

Math. 136. Matrix Inversion and Decomposition. A semester senior course in the numerical treatment of matrix inversion and eigenvalue problems. This has been taught either from Householder's "Principles of Numerical Analysis" or from my unpublished notes, "Theory of Selected Methods of Matrix Inversion and Decomposition."

The course presupposes the theory of equations, but nothing of higher algebra. Much of the time is therefore devoted to background material on the algebra and analysis of linear transformations in finite-dimensional space.

Math. 137. Numerical Methods in Differential Equations. A semester senior course on the numerical solution of ordinary differential equations, based on Milne's "Numerical Solution of Differential Equations." This is the only undergraduate course with low attendance.

Math. 139. Automatic Digital Calculators. A semester senior course. It starts with idealized electrical and electronic elements and the synthesis of computer components. Computer organization, binary arithmetic, some numerical analysis, and--most of all--coding comprise the rest of the course.

Math. 140. Logic of Application of Automatic Digital Calculators. A semester senior-graduate laboratory course on problem organization and logic; Math. 139 is presupposed.

Engineering extension series. One year the Engineering College sponsored an extension series entitled "Mathematics for Modern Engineering." A number of talks were on numerical analysis, of which several were given by members of our senior staff.

Master's papers. A number of master's candidates take several of the above courses, and perhaps one of the graduate seminars listed below. Then they want to do a master's paper in numerical analysis. For the better terminal students this is a very satisfactory activity, which our staff is happy to sponsor. Several of these papers have been expositions of numerical methods.

Now they are tending more to involve a substantial SWAC code—
with perhaps some numerical experiment.

The above courses are regularly offered both as ordinary U.C.L.A. courses, and as extension courses. There is an officially recognized curriculum in numerical analysis at the undergraduate level, leading to a Certificate in Numerical Analysis. It is pursued by a number of students as a terminal program, mostly in evening extension classes. It requires 24 units of credit, including Math. 135, Math. 136, Math. 139, Math. 140, an engineering course on analog computing, and two electives from among courses in statistics, probability, basic electronics, special problems in mathematics, differential equations, transform methods, servomechanisms, and sampled-data systems and digital computers. Most students in the Certificate program already have a bachelor's degree in some field.

2. Educational activities at the Predoctoral-postdoctoral level

As indicated earlier, we feel that the student who wants to become a serious mathematician in numerical analysis should, above all, learn the fundamentals of classical mathematics. We therefore discourage specialization in numerical analysis courses. We have declined even to set up a special syllabus in numerical analysis for the Ph. D. preliminary examination. Our students have tended to pay special attention to the calculus of variations, both for the applicability of the subject and because the U.C.L.A. faculty members in that area happen to be more interested in numerical analysis than some of the others.

Applied mathematics is, of course, quite different in spirit from abstract mathematics. Applied mathematicians must be able to think and talk like their colleagues in other fields. My impression is that the student who stays close to abstract mathematics is not likely to make a good applied mathematician. On the other hand, students with an interest in and aptitude for applied work do not need to be pushed into taking applied courses; they will automatically visit other departments and take work there. But the potential applied mathematician needs to be urged to absorb all the fundamentals he can. We hope that our seminar program at Numerical Analysis Research supplies enough atmosphere of applied mathematics, particularly to students with our graduate assistantships.

Math. 251. Computational Aspects of Linear Problems. A semester graduate seminar presupposing higher algebra or Math. 136, and also Math. 139 or equivalent. Analysis of numerical methods for inverting matrices, solving systems of linear equalities and inequalities, and linear games. Special attention to methods suitable for digital computers. (First offered in 1954-55; to be offered again in 1955-56.)

Math. 252. Computational Aspects of Partial Differential Equations. A semester graduate seminar presupposing advanced calculus and Math. 139 or equivalent. Some time must be devoted to the theory of partial differential equations. Finite difference methods: convergence, stability, error analysis, relaxation techniques. Methods based on minimum principles. Solutions in series form. Numerical solution of integral equations. Role of digital computers. (First offered in 1954-55; to be offered again in 1955-56.)

Math. 253. Computational Aspects of Statistical and Discrete Variable Problems. A semester graduate seminar presupposing some probability or statistics and Math. 139 or equivalent. Computational aspects of sampling and analysis of variance. Generation of random deviates and Monte Carlo methods. Design of experiments and numerical simulation. Exhaustive searches and other attacks on discrete variable problems. (First to be offered in 1955-56.)

Math. 260. Numerical Analysis Seminar. An opportunity, rarely taken, to get graduate credit for the seminar work listed below.

Coding course. About three times a year an informal three-week SWAC coding course (no credit) is offered, aimed at graduate students, faculty, and other mature persons who might like to use SWAC. It always draws a good audience.

Special seminar series. At various times, especially in the summer sessions, we have a connected seminar program for our graduate assistants, staff, students, and others, with speakers from our staff, students, and from other users of SWAC and similar machines in the area. These have been held on linear programming, asymptotic series, partial differential equations, approximation of functions, orthogonal polynomials, Monte Carlo methods, finite projective planes, and on combinations of such topics.

Numerical Analysis Seminar. Once or twice a week throughout the academic year we have talks on assorted topics of numerical analysis by students, staff, and visitors.

Colloquium lectures. From once a week to once a month we sponsor addresses by visiting mathematicians on subjects usually related to numerical analysis.

Symposia. With partial sponsorship from our organization or its predecessor the Institute for Numerical Analysis, several special symposia and a Mathematical Society Symposium have been held in our area. Topics have included: numerical analysis of the future, conformal mapping, linear algebra, and numerical analysis in general.

Interviews. Our staff members frequently discuss scientific computing problems with U.C.L.A. faculty and students, and with mathematicians from government and industry, acquainting them with the literature and otherwise trying to help. We do not want to be a consulting service, but feel that continued contact with practical problems is essential to our research and teaching.

Thesis guidance. Our senior staff members guide a number of doctoral theses in mathematics, engineering, meteorology, and physics. Outside of mathematics we usually give guidance in the computational aspects of a physical problem. For mathematics students our stress on their learning classical mathematics has naturally led most students to write their theses in areas other than numerical analysis. One statistics student wrote on Monte Carlo methods. Some students of Professors Hestenes and Tompkins in the calculus of variations have come close to numerical problems, as has at least one working under Professor Sokolnikoff. It is probable that our graduate seminar series will develop students with enough background to do a thesis in numerical analysis proper.

Graduate Assistantships. One of our most significant educational functions is an apprenticeship program for graduate students. We have between seven and nine graduate assistants at all levels, and ordinarily support them until they attain the Ph. D. degree. Two or three are selected each year after a nation-wide campaign for applications. Most graduate assistants are on a half time appointment, and take a full degree program at the same time. We expect approximately 10 hours per week of helping our laboratory with elementary numerical analysis, with computations, with writing, etc. In addition, we expect approximately 10 hours per week of learning advanced numerical analysis, participating in advanced courses and seminars, and helping the senior staff with directed research on challenging problems of scientific computation. Such appointments pay between \$1728 and \$2256 per eleven months, and outside employment is not permitted.

Two or three of our graduate assistants work on a three-quarter time basis. Such students spend 20 hours per week helping to maintain the computing facility by such work as circuit checking, tube testing, writing and/or checking basic SWAC codes, and helping our staff with elementary numerical analysis, with computations, and with writing.

Our graduate assistants are all familiar with SWAC and use it. Some are experts, pioneering the use of digital computers. They all have an unparalleled opportunity to immerse themselves in digital computing for a few years, and SWAC is always available

to them. I feel sure that these men will be highly qualified to assume positions of leadership in the computing field soon after their graduation.

It should be added that some graduate students from other departments (notably physics and chemistry) are immersing themselves in digital computing as deeply as our own graduate assistants. Occasionally it appears that these volunteers contribute more to the maintenance of our facility than some of our own paid assistants!

If we were to add another graduate seminar, I think it should be on the computational aspects of the approximation of functions, a rather neglected subject. The seminar should include orthogonal polynomials over arbitrary distributions, Chebyshev and least-squares approximations, interpolation in the real and complex domains, finding the zeros of polynomials, and relations with continued fractions. Digital computers should be kept in mind all the time.

August 1, 1955