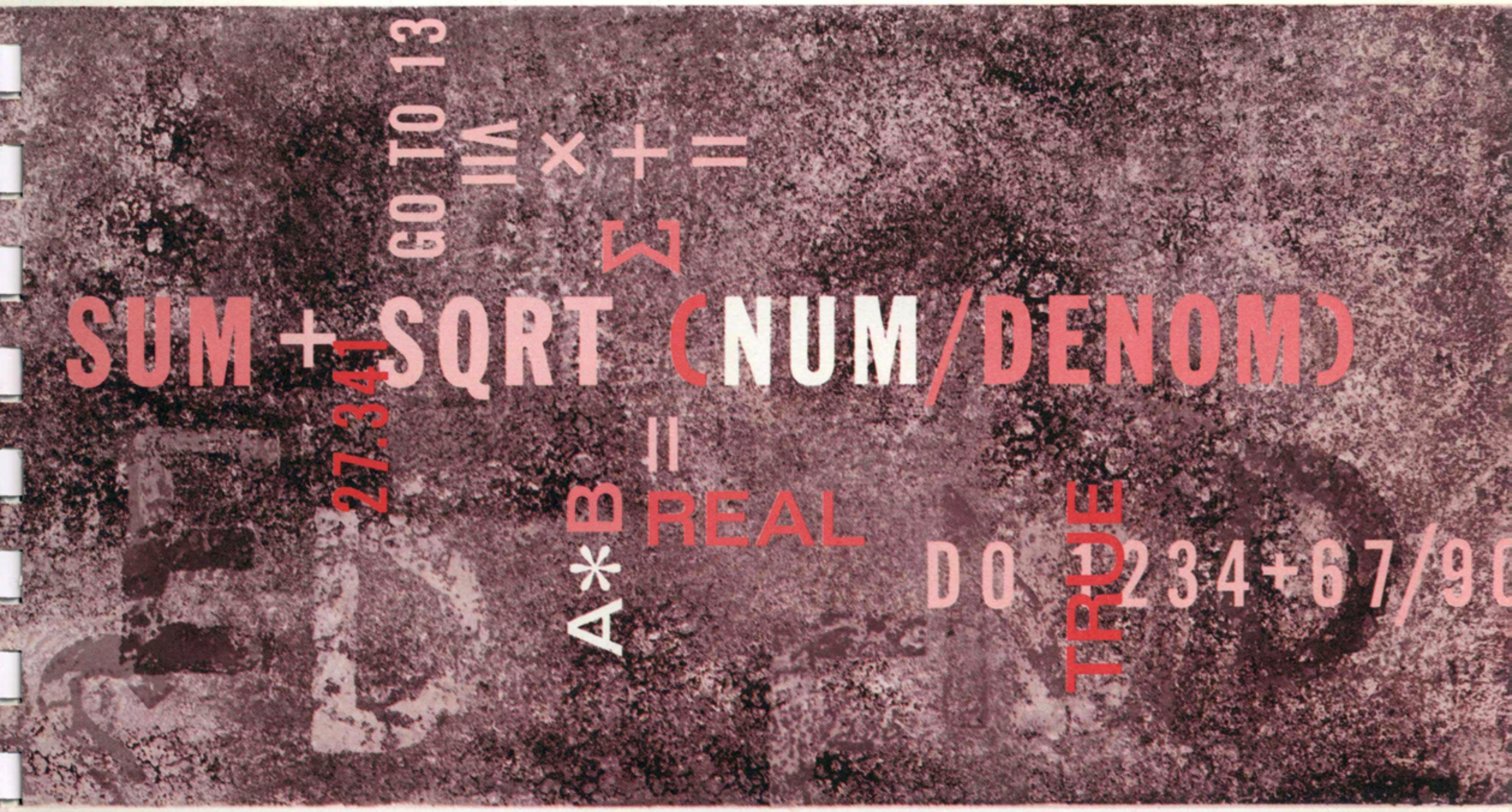
stanford university computation center



STANFORD UNIVERSITY COMPUTATION CENTER
DEDICATION

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August 9, 1963

The new Computation Center of Stanford University was dedicated on Friday, August 9, 1963. There were tours of Pine and Polya Halls, an outdoor luncheon with addresses by Dr. Richard Hamming and Professor George Forsythe, and a technical address by Professor George Polya.

In this booklet are collected the substance of the talks as a record of the occasion. It is too bad that it is impracticable to record also the interesting explanations of the buildings and computers given by many staff members of our Center.

A list of those attending the dedication is given also. We were very sorry that a lack of space made it impossible to invite every one who might have enjoyed the occasion.

George E. Forsythe
Director

RECORD OF THE LUNCHEON ADDRESSES

MR. FORSYTHE:

My name is George Forsythe, Director of the Stanford University Computation Center. The weather was arranged in an attempt to shorten my remarks. [Most unusual for August, it had rained lightly up to a few minutes before we sat down for an outdoor luncheon.] We've never had 275 people in to lunch before.

To welcome you on behalf of the President and the Board of Trustees will be Dean Albert Bowker. Mr. Bowker is Dean of the Graduate Division at Stanford. This position is often a rather routine one, but under Mr. Bowker's leadership it has become extremely important. At the very least it corresponds to that of Director of Research. He has taken the initiative in the rapid growth of our Computation Center in the past three or four years. I can't tell you how much his dynamic and far-seeing leadership have meant to us.

Our good fortune in having Mr. Bowker is unfortunately about over, for the rest of the world has found out how good he is. Starting in the fall, he will be the Chancellor of the City University of New York. We're glad for him but sad for us. Mr. Bowker:

MR. BOWKER:

As Professor Forsythe has said, this is my last opportunity to welcome a group on behalf of the University and fortunately I cannot think of an occasion on which I would rather have that responsibility. I am proud of our Computation Center. It has grown in a relatively short period to be important to the University and to stand among the best university computation centers in the country. If any credit is due to me, it is that I had sense enough to hire George Forsythe as Director.

Of course, a great complex of machines, men, buildings, trees, and flowers such as we see here is not due to the efforts of one or two people. It is a result of hard work and the generosity of many. Probably most of the credit really goes to the eminence and achievements of members of the Stanford faculty. Their active research in science, social science, engineering, medicine and business have on the one hand created the demand for these facilities, and on the other hand their unquestioned accomplishments have influenced those who are in a position to help us. I should particularly like to mention the close cooperation between the Center and the Stanford Electronics Laboratory, and most recently, the cooperation in planning between the Center and the Stanford Linear Accelerator Center. The growth of facilities at the University and at Stanford Research Institute have been jointly planned and we are grateful for their cooperation.

As most of you know, the Federal Government is a great help to universities in support of science. We will hear more about the gifts from the National Science Foundation later, but I should like to express thanks to that agency and to the Office of Naval Research for their strong support.

What most of you probably do not know is that the acquisition of pieces of equipment costing in the millions is almost invariably associated with substantial corporate gifts and educational allowances. We have had IBM equipment in our Center for nearly ten years, starting with the CPC and the 650. I believe we were one of the first participants in IBM's educational program; the Corporation has been extremely generous to us in our recent negotiations for the 7090 and deserves our deepest gratitude. Mr. Rodgers and Mr. Kocher of IBM are present. I hope you will have an opportunity to meet them later. Our association with the Burroughs corporation started later, with the installation of the 220 at Encina Hall. It has been an extremely pleasant relationship and we must express our appreciation to the corporation for its great generosity and cooperation with Stanford. Mr. Eppert, President of Burroughs, is here and I hope you will have a chance to meet him later. We have just started our relationship with the Digital Equipment Corporation, who manufacture the PDP-1, and we look forward to this association with great enthusiasm.

I am glad to see Vice President Rathbun of the First National Bank of San Jose. Their cooperation has been very helpful in connection with our 220 installation.

Finally, no meeting in this beautiful setting could be complete without mention of Mr. Joseph Eichler. Many of you who are visitors and new to this area may not know that the name of Eichler is synonomous with economical, impressive, and esthetically attractive building. We express gratitude to Mr. Eichler for carrying out these fine traditions and for carrying them out so expeditiously. Mr. Eichler is here with some of his staff.

Finally, I want to thank you again for coming. Stanford is honored to have you here. This is a great occasion in the life of the University.

MR. FORSYTHE:

We are blessed with many benefactors. One of the solidest is the United States Government. Their help comes in two ways. Various agencies like AEC or NIH or NSF or ONR have contracts with individuals or groups at Stanford, and they may pay for some computing time as part of the contract. Useful as these sources are, they could not justify a major computing installation like this. In particular they could not make possible the use of the computer for university research which lacks a rich sponsor, nor for Education. Here the National Science Foundation has stepped in and given us very substantial overall backing for a computation center. This has occurred three times--in 1956, 1960, and 1963. We are very grateful. We are happy to have with us today Dr. Robert Owens, of the National Science Foundation. Mr. Owens:

MR. OWENS:

The effectiveness of a facilities grant from the National Science Foundation strongly depends on the overall support given the facility by the home institution. The expected extent of this support is one of the factors which influence the decision to make such a grant.

The obvious support given this new facility by Stanford University, as evidenced by the outstanding staff, the computing equipment, and the new buildings, is very reassuring to those of us in the Foundation who were involved.

I am pleased to represent the Foundation at this dedication ceremony and wish Stanford and you, Professor Forsythe, every success in those computer oriented research programs which will utilize your new facility.

MR. FORSYTHE:

Besides our debt to organizations, this Computation Center owes a lot to individuals. Most of our past and present staff have worked their heads off to build a first class service to Stanford research and education. I must mention two or three who are no longer with the Center, but who added so much: Mrs. Helen Van Heusen, who for six years did all the key punching, scheduling, instruction in card equipment--everything; Mr. Robert Gordon, who did much to carry us from an IBM 650 center to a Burroughs 220 shop; Mr. Roger Moore, who did the lion's share of creating a compiler for the IBM 7090 which accepts all programs written in the 220's main language. This masterpiece spared the whole campus a difficult language change.

Turning to those still present, I must first mention Professor Herriot, who directed the Computation Center single-handedly for several years. And Mr. Cole and Mr. Langle and ..., but where can I stop? ... all of you!

Let me say how much we owe to our users. Some of them have contributed first class systems and programs for the library. Many have given us criticism and advice, usually needed. And a great many contribute to our budget regularly but quietly by using the Center.

Finally, we should acknowledge our debt to the international fraternity of computer folk. I don't know whether you understand that all that hardware would be virtually useless without the programs and

and systems called "software." And the real cost of that software (i.e. manhours invested in it) is approximately equal to the hardware. Now, fortunately, the tradition has grown up of exchanging this software freely among computer centers around the world. (There are some exceptions.) I don't happen to know of any other field of technology where such an essential part of the business may be borrowed from one's colleagues and competitors.

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ADDRESS BY MR. FORSYTHE

Well--acknowledgments seem important to me, because I've become so involved in the administration of the Center. But I know they can sound dull to active minds. I'm sure you're wondering what we actually do with this Computation Center.

There are three roles of computing in a university. I don't put these in any particular order of importance.

First: research and development, to increase our understanding of Computer Science, and thus indirectly to increase our capabilities.

Second: computer service to the university community.

Third: education of the Stanford students in computing.

Stanford has been active in all these roles, and will become more active in all of them. A major Computation Center is indispensible to all these areas. Let me elaborate them.

Our oldest and strongest area of research and development in computer science has been in numerical analysis--that is, the design and analysis of mathematical methods for solving scientific problems with computers. As a direct result, Stanford's programs in certain areas are among the best in the world. I'm thinking especially of matrix programs. We are moving ahead with numerical analysis. I say relatively little about it now, partly because I hope its purposes and methods are understood and accepted by most of you, and partly because of a certain reverse bias--it happens to be my own field.

We next picked up strength in programming, and especially in writing compilers--programs that translate from algebraic languages into machine code. Inspired by some excellent Burroughs 220 programs and by Bob Barton, some of our undergraduate and graduate students produced the fastest and most flexible compiler we know of for the IBM 7090. It is proving extremely popular.

With the arrival of Professor John McCarthy from M.I.T., we automatically became a center for List Processing programs, and the improvement of these for the IBM 7090 is the subject of a nation-wide effort centered at Stanford.

Our interest both in compiling and in scientific algorithms led very naturally to our interest in the Burroughs B 5000. We feel a strong commitment to the international ALGOL movement, and want to help make that language a working tool for computing everywhere.

Mr. McCarthy brought us two more new interests: time-sharing and artificial intelligence. In the early days of computing, a person could obtain the full time of an automatic computer. The collaboration often took 100 per cent of the person's time but perhaps only 1 per cent of the computer's time (the machine waits for the person to think). As machines got faster and computing persons grew more numerous, sheer economics forced the persons to waste less computer time. So they were required to prepare their programs entirely in advance, stack them into a big batch, and wait for the computer to handle the batch. Thus the computer was used 100 per cent of the time, but the man with a problem was forced to wait much longer.

The basic idea of time-sharing is to take 5, 10, or 200 persons, and put them all into direct communication with what seems to each to be the whole computing machine. In fact, the computer serves them all in turn in a fast round-robin. The computer is busy all the time; a person waits for only a few milli-seconds; and balance is again restored. It's like a master playing chess with 50 duffers at once.

Now most people agree that this time-sharing business is the future of computing. But there is wide disagreement on how best to carry it out. Stanford is engaged in research and development of what we think is a very good method. The first planned phase involves heavy use of a PDP-1 computer (made by the Digital Equipment Corporation) and tying the PDP-1 to the IBM 7090. The PDP-1 has been made into an excellent secretary, and can service many customers easily. The 7090, with its great size and speed, can do the heavy data processing and computation which would be too much for the PDP-1. The team should prove to be very powerful indeed.

Artificial Intelligence is the use of computing machines as extensions of the human mind, just as power tools are extensions of human muscle. In the last ten years we have become more and more aware that computers could prove theorems, play chess, do algebra or calculus, and carry out other activities that simulate human thinking. Out of sheer optimism, and out of the necessities of batch processing, there was wide expectation that computers alone would take over a substantial amount of productive thinking. This dream--inspiring to some of us, terrifying to most people--that machines could replace thinkers--has not yet been realized, although it has given us many valuable by-products. But now that time-sharing is recognized, there is a movement back to seeing what human beings and machines can do working together. With the programs generated over the past decade, and with the new time-sharing tools, the time is ripe for a rapid increase in the practical results of artificial intelligence. Let me say only that Stanford is at the forefront of these developments.

Besides work at the Computation Center, there is work on another aspect of Artificial Intelligence in Electrical Engineering under Professor Widrow.

Time prevents mentioning other areas of computer science, which are less represented at the Computation Center. It is our intention to build them up also, as persons and money become available. They include computer design, information retrieval, data processing, etc.

In our computer service to Stanford, we are running the best shop we know how. We got many lessons from Dr. Hamming on this matter two years ago, and we remember them well. We try to provide efficiently run hardware, and many useful library programs. We teach a few languages as often and as well as we can, and we provide 40-hours-a-week consultation on languages to our users. We help our users find programmers to hire. Our senior staff consult on computing methods. But there is one thing we don't like to do--and that is to provide a complete problem-solving service, or a complete programming service. There are three reasons: First, we don't want to build a large empire of people and supervisors. Just the natural growth of this revolutionary field is fast enough to exhaust us. Second, we know that our competence in a particular field can never be comparable to that of the department involved. Third, we are missionaries--we want our users to appreciate and understand and become competent in the techniques necessary to use computers naturally and gracefully. You would be rather surprised, however, at how hard it can sometimes be to convince people that the Computation Center should not take responsibility for solving their problems!

There are exceptions, of course. For example, Mr. Hockney has been working almost full time with Professor Buneman at solving problems in plasma flow, with extremely good results. Mr. Carter has helped many persons extensively with their data-processing problems.

One role of our Computation Center at Stanford is perhaps unexpected. As Mr. Lamar puts it, we provide a sort of academic clubhouse. In these days of increased specialization it is more and more rare for persons from different disciplines to even see each other. Over here at our key punches and our coffee shop these people can interact. I know that some problems are solved without even an approach to a computer, by means of this interaction. We are very proud to be an antidote for overspecialization.

The third of our areas is Education. In addition to the rather direct training in programming offered by the Computation Center, we have formed a special subdepartment at Stanford called the Computer Science Division. This is charged with most of the general teaching about computing, but not all of it. (There is some in the Graduate School of Business, and some in the School of Engineering.) We offer undergraduate introductory courses in computing and numerical analysis. We expect about 600 to 700 students in the first programming course during 1963-64. We will have about 70 students enrolled in a Master's curriculum in Computer Science. We direct theses and do advanced teaching for students in numerical analysis who take a Ph.D. in Mathematics. (There have been five so far.) We later expect to have a number of Ph.D. students in Computer Science, at first under the interdepartmental program called "Graduate Division Special Programs."

The graduate level programs are quite new. We are feeling our way along. The forces of tradition in a university are considerable, and we don't presume the wisdom to know exactly when it is desirable to try to formalize a new field. We know it's coming; we just don't know exactly when it will have arrived.

Let me say this about the undergraduate courses in programming and numerical analysis. We believe that both should be heavily laboratory courses. They are concerned with solving problems on computers, and these courses involve actually <u>doing it</u>. In the autumn quarter we expect 400 to 450 students in the introductory programming courses. Each student will solve about five or six problems on a computer. Each problem will require four passes, on the average. Thus one course alone will need about 10,000 passes through a computer during a 10-week quarter. When you consider that homework is forbidden the last week, and that it's hard to get started the first week or two, this means that most of the 10,000 passes will occur during a seven-week period. This is a massive demand on a Computation Center, something like 300 problems per day. I marvel that our people can do it. Our total work load for spring quarter was 22,000 jobs. I don't believe any other university is providing anything like such service to such a large percentage of its student body, though perhaps the University of Michigan runs as many problems in total.

Once the students learn to use a computer gracefully, many continue to use it later on--for homework, as workers on research projects, for their Ph.D. dissertations, and so on. We have them hooked.

To fit these 200 to 300 student problems per day into the normal operating schedule of a computer requires extraordinarily facile operating systems, compilers, and operating personnel. The computer manufacturers have provided some of these. We have provided many of them ourselves.

Our need for a B 5000 in a shop that already has a 7090 is largely due to the mass of problems that we generate at Stanford. We believe that the B 5000 is well adapted to this massive demand. Its use will free the 7090 in part for the development of the time-sharing systems that I mentioned earlier.

Thus, in spite of the immensity of the computing power that sits in Pine Hall, I assure you that it will be used heavily, and well.

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MR. FORSYTHE:

Before introducing the main speaker of this luncheon, let me call attention to the remainder of the program. After Mr. Hamming speaks, you are invited to tour our Center.

As you know, we feel most grateful that Professor Polya has consented to have us name this building for him. He is one of the world's best known and best loved mathematicians. Since his official retirement ten years ago he has actively continued research, teaching, and writing. Besides his many books and papers in mathematics and some in numerical analysis, he has published several books on mathematical discovery and heuristic reasoning in mathematics. While Mr. Polya does not consider himself an expert in computing, I believe that his work on heuristics will give many suggestions on how machines may simulate creative behavior. He may thus find himself a founder of artificial intelligence!

Everyone would appreciate it if you would stand, George, so that you will be known to all.

At 3:15 Mr. Polya will give a numerical analysis colloquium in the lecture room of Polya Hall. This is a talk for the mathematically inclined; it's not a popular lecture.

In September of 1960 the Computation Center, then in Encina Hall, received a guest professor. He came from the Bell Telephone Laboratories to write a book on numerical analysis in precisely 12 months. He did this on schedule, and the book is widely acknowledged to be one of the most important in the field. While he was here, Dr. Richard Hamming took an active interest in everything that any of us were doing. He would drop by the machine room each morning, and cast a critical eye at the arrangement of the consoles, and at what the operators or engineers were actually doing. If the machine ever stopped between programs he would ask embarrassing questions as to why we were wasting good time. If the programmer expected the operator to depress a switch for him, Mr. Hamming was aghast at having an unrecorded action in the program. If programs failed to have effective restart procedures built into them, he chastised us.

Then he would walk into any office, and ask us what we were doing that was <u>really</u> important. What was worthy of a Nobel prize?

He regularly had lunch with actual or potential clients, learned their complaints and desires, and then told us. He sided with some of our users against us, and said we weren't responsive to their needs. Then later he would side with us if the user got unreasonable.

He gave lectures everywhere on the Computer Revolution. He taught a mature course at a mature rate of speed, and had course notes available in advance of every lecture. He checked up that his large class actually read the notes before class.

He criticized the mathematics curriculum for devoting too much attention to analysis, and not enough to discrete-variable work, in view of modern trends in the applications.

You can see that Mr. Hamming was running a one-man mission to be Everyman's conscience, and to improve the world of computing.

Who was he, this man? He was a pure mathematician by training, receiving a Ph.D. from Illinois during World War II. He taught some, and then entered industrial work at Los Alamos, and later moved to the Bell Telephone Laboratories. He soon achieved international fame for devising what are called "Hamming error-correcting codes." He worked in numerical analysis for the decade of the 50's. From his book, you will find what he means by numerical analysis. It is, in fact, the simultaneous application of everything one could possibly know to the solution of, say, an engineering problem. One should use the experimental methods and analytical tools of his own discipline, and combine them with mathematical analysis (either exact or approximate), with numerical methods on a digital computer, with simulation on a digital or analog computer, and even use pure intuition. Moreover, one should be facile at mixing these methods, for each will reinforce the other. Mr. Hamming follows the trend of modern mathematics in urging one to forget about special tricks, and develop general attacks on classes of problems.

As for computing, I think his famous motto expresses his point of view better than any thousand words: THE PURPOSE OF COMPUTING IS INSIGHT, NOT NUMBERS.

I give you Mr. Hamming:

THE COMPUTER AND THE UNIVERSITY

MR. HAMMING:

This is not just another dedication in the busy life of a University: rather it is a large step forward into the world of information processing, and those who have made this possible are to be envied and congratulated.

It has often been maintained that the heart of a University is the library, the storehouse of knowledge. The classical functions of the University were twofold: that of adding to this store of information, hence the importance attached to research and publication, and that of transmitting the methods of using the accumulated information, hence the importance of teaching.

Our present civilization is developing more and more complex methods of combining information to produce new information, as well as how to use the information in practical situations. Thus a storehouse of information is no longer the single center of the University; the University must now also supply the tool for combining and manipulating information, namely it must supply a large scale, general purpose, digital computer. Thus the two tools of information, the library and the digital computer, are becoming jointly the heart of the University. I am not speaking of the computer as merely an information retrieval device to be used by the library staff, I am speaking of it as an information processing machine, a tool for research, a means for combining ideas and information to produce new ideas and new information.

When I say a computer produces new information it is necessary to speak carefully. Professor Nagle has coined the expression, "logical novelty vs. psychological novelty." Logical novelty is something new which does not follow from the assumptions, while psychological novelty is a consequence of what has been assumed but which appears to be new to the human. Lest you think psychological novelty is trivial let me point out that in High School Geometry, for example, the postulates and rules for combining them are the logical novelty, and all the theorems are only psychological novelty. Indeed, insofar as mathematics is a deductive process it is only the postulates that are the logical novelty, and all the rest is mere psychological novelty. Thus psychological novelty is not a trivial matter.

It would be wrong to conclude from these remarks that the computers are of interest mainly to mathematicians; indeed, computers have had as yet very little influence on mathematical research. Most of the use of computers to produce new results has been in other areas where the machine is often given, in mathematical symbols, a model of a situation, and is used to produce various consequences of this model.

This description suggests that you must have a clear picture of your model before you approach the machine, and in a sense this is correct - the machine must be given a definite program of instructions to follow. But the set of instructions may include the use of random trials while searching for some goal. Indeed it is surprising how useful a computing machine can be even in areas which at first glance seem to be vague and ill-defined. Thus, to take an important example, we are beginning to investigate models of creativity in various areas. Our present culture puts great stress on originality and creativity, and that is probably why research on creativity is so fascinating. How far we will progress remains to be seen, but the start is hopeful; for the first time in history we have a powerful tool to explore the problem.

To use a library productively requires far more than training in looking up a book in a card catalog or using standard references, so also to use a computer productively requires far more than training in some computer language; both require a highly trained mind which understands the central ideas of the field, mental habits for recognizing and organizing relevant material, and the self-discipline to carry out the work and to present it to one's peers in a suitable form and in good taste. It is the habit of viewing a field properly, and of asking suitable questions, that marks the trained computer expert.

Thus one of the first tasks of a computing center is to train people not only in the formal use of the computing machines, but, more importantly, in the art of using the machines wisely. Secondly, it must develop and extend the art of using these powerful new tools of the mind. As if these two tasks were not enough, a computing center must also maintain a service so that others may use the machines in their own research. To provide such a service requires machine hardware, the so-called programming "software", and a great deal of consulting with other members of the University staff.

We live in a changing world. In the recent past the main problems of our culture have centered around the actual making of material objects - farming, manufacturing, etc.; we are rapidly approaching a world in which the information of how to do something is more important and difficult to acquire than is the final doing. For example, consider the "man in space program" - how little is to be spent on the actual flight and how much on getting the information about how to do it! It is clear that in this future world the computer, because of its ability to handle and transform information, will play a central role.

I have emphasized the importance of computers, but let me make one point clear; as you wander about these lovely new buildings and grounds and watch the sparkling new machines with their flashing lights, you should not forget that it is the humans who use them that give the machines their importance. One does not judge a library by the number of books checked out, and one should not judge a computing center by the machine hours used; their values lie in the quality of the questions asked, not in the quantity.

The wise use of computers requires, as I indicated, not only formal training on how to control the computers, but more importantly a whole new view of the world and its ideas. You are all aware of how Darwin's idea of evolution has penetrated into fields remote from biology, how often today we ask: "How did this evolve?" If I had to summarize in a single word the influence of computers on the world of ideas I would say "Algorithm," meaning a detailed, step-by-step, description of how the various parts are inter-related. The world "algorithm" does not describe everything involved in the computer revolution, just as the word "evolution" does not summarize all of modern biology, but in both cases the words tend to show the power of the central idea and its ability to spread and affect the views of apparently remote fields of human thought.

I have used the analogies of a library and of evolution to try to bring home to you that this is not just another building or piece of equipment, such as a two mile linear accelerator, created for the benefit for some special interest group, this is a fundamental contribution to the whole of the intellectual life of the University.

Let me again congratulate those who have made it possible, and in particular Professsor George Forsythe, its present director.

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ABSTRACT OF

PROFESSOR POLYA'S ADDRESS

In the afternoon Professor Polya gave a technical talk in room 111 of Polya Hall. He was introduced by Mr. Herriot, Professor of Mathematics and Computer Science.

MR. HERRIOT:

It is a great pleasure to welcome all of you to this, the technical portion of our dedication program. While Professor Polya's lecture was advertised as not a popular lecture, Professor Polya is always a popular lecturer. It has been a great privilege and pleasure to have had Professor Polya as a colleague at Stanford for over 20 years. I am sure that Professor Polya would not claim to be a numerical analyst but much of his mathematical work has been of interest to numerical analysts. He has written papers on quadrature, on the Graeffe process and in his work with Professor Szegö on "Isoperimetric Inequalities in Mathematical Physics" he was concerned with the problem of estimating quantities difficult to calculate by means of the other more easily calculated quantities. As computing power increases, the class of quantities easy to compute is ever widening. It is indeed a great pleasure to introduce Professor Polya to you and to have him speak to us in Polya Hall. Rarely are the names of the hall and the lecturer the same. He will speak to us about "Some Numerical Applications of the Convexity of Functionals."

The following brief abstract was written by Mr. Forsythe.

ABSTRACT OF ADDRESS: Mr. Polya spoke on a method of obtaining exact upper and lower bounds for certain real-valued functionals of domains from relatively few data. As an example, he used the principal eigenvalue λ of a triangular membrane. If D is a domain with boundary B, the principal eigenvalue λ of the membrane D is the least number such that

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \lambda u = 0 \qquad \text{in } D$$

and

$$u = 0 \qquad \text{on } B \, .$$

The value of λ is important in studying the behavior of solutions of the heat equation, in analyzing wave guides, and in estimating the rate of convergence of certain iterative methods for solving the Dirichlet problem for a region.

The exact value of λ is known for triangles of only three different shapes: the 45-45-90, 30-60-90, and 60-60-60 triangles. These are precisely the three shapes of triangular tiles which can be used to cover the whole plane. The research reported here used this information to get bounds on λ for all isosceles triangles.

Let an isosceles triangle have base 2 and altitude $h = 1/\sqrt{\tau}$. Let $\lambda(\tau)$ be the fundamental eigenvalue of the triangular membrane corresponding to τ. In addition to the 45-45-90 and 60-60-60 triangles mentioned earlier, there are two limits of isosceles triangles for which $\lambda(\tau)$ is known--the triangles 90-90-0 (the infinite half strip $\tau = 0$) and 0-0-180 (the collapsed isosceles triangle $\tau = \infty$). The values of $\lambda(\tau)$ are tabulated here:

τ	:	0	$1/3$	1	$\sim\infty$
$\lambda(\tau)$	:	$\frac{\pi^2}{4}$	$\frac{4\pi^2}{3}$	$\frac{5\pi^2}{2}$	$\sim \pi^2 \tau$

The following facts are known:

(A) $\lambda(\tau)$ increases, as τ increases.

(B) $\lambda(\tau)$ is a differentiable function of τ; moreover, $\lambda'(\tau)$ can be computed for $\tau = 1/3$ and $\tau = 1$.

(C) $\lambda(\tau)$ is convex "from above" ($\lambda''(\tau)$ is nonpositive wherever it exists.)

(D) Of all triangles with a given area, the equilateral triangle has the minimum λ.

For proofs of these facts by the method of "transplantation", see G. Polya and M. Schiffer, "Convexity of functionals by transplantation," Journal d'Analyse Mathématique, 3, 245-345 (1953/54).

In the remainder of the talk, Mr. Polya showed what good bounds for $\lambda(\tau)$ can be obtained from just the above table and facts (A), (B), (C) and (D). The results are summarized in the following table, in which we take $a = 1$:

The following are tabulated:

(1) $h/a = 1/\sqrt{\tau}$

(2) the lower bound L

(3) the upper bound U

(4) the approximate value $\frac{2UL}{U + L}$, which is the best estimate possible for $a^2 \lambda = \lambda$

(5) the maximum possible relative error of (4) as an estimate of the true λ .

The research and the table reported by Mr. Polya were done by a former student, Grove C. Nooney. See "On the vibrations of triangular membrances," Tech. Report 35, Contract N6ori-106, (NR-043-992), Department of Mathematics, Stanford University, Oct. 22, 1953.

TABLE: isoceles triangle, base 2a, height h.

(1) h/a	(2) lower	(3) upper	(4) $a^2\lambda_1$	(5) error %
0	$a^2\pi^2h^{-2}$	$a^2\pi^2h^{-2}$	∞	
0.5	54.28	61.69	57.75	6.4
0.6	42.22	46.61	44.30	4.9
0.7	34.95	37.51	36.18	3.5
0.8	30.23	31.61	30.90	2.2
0.9	26.99	27.57	27.28	1.1
1	$\frac{5\pi^2}{2}$	$\frac{5\pi^2}{2}$	24.67	
1.1	21.71	22.53	22.12	1.9
1.2	19.46	20.29	19.87	2.1
1.3	17.71	18.26	17.98	1.5
1.4	16.32	16.65	16.48	1.0
1.5	15.20	15.35	15.27	0.5
1.6	14.25	14.29	14.27	0.1
1.7	13.41	13.41	13.41	0.0
$\sqrt{3}$	$\frac{4\pi^2}{3}$	$\frac{4\pi^2}{3}$	13.16	
1.8	12.66	12.67	12.67	0.0
1.9	12.00	12.05	12.02	0.2
2.0	11.40	11.51	11.46	0.5
2.1	10.85	11.06	10.95	0.9
2.2	10.36	10.66	10.51	1.4
2.3	9.91	10.31	10.11	2.0
2.4	9.50	10.01	9.75	2.6
2.5	9.12	9.74	9.42	3.3
∞	$\frac{\pi^2}{4}$	$\frac{\pi^2}{4}$	2.47	

List of those accepting invitations to the Dedication[*]

Adams, Dwight B.	Business Office
Allen, Peter C.	News and Publications
Andersen, Christian J.	Staff
Anderson, Virgil	Speech pathology and audiology
Angell, James B.	Electrical Engineering
Anliker, Max	Aeronautical Engineering
Armstrong, Earl F.	SRI
Atkinson, Richard	Institute of Mathematical Studies
Atwater, Don K.	Burroughs
Augustine, Virginia T.	Staff
Axt, Richard	Research Administration
Bacon, Harold	Mathematics
Baillie, Paul	IBM
Baker, James	Radiation Laboratory
Barlow, Mrs. Paul	Staff
Barton, Robert	Private Consultant
Bates, Frank	Staff
Baxter, Mrs. Wilbert	Staff
Bolton, Wallis	
Bowker, Albert H.	Dean of the Graduate Division
Boyd, John B.	Eichler Homes
Brandt, Karl	Dir. Food Research
Brown, J.H.U.	NIH
Buneman, Oscar	SEL
Bunker, John	Anesthesia
Burton, Edith	Staff
Businger, Peter	Staff
Butler, Harold	SLAC
Calhoun, Everett S.	SRI
Campbell, W. Glenn	Hoover Institute
Cannon, E. W.	Bureau of Standards
Carter, Sr., Irval W.	Public School Administrator
Carter, Joseph O.	Staff
Carter, Mrs. Joseph O.	
Caswell, Peter	C.E.I.R.
Charles, Mrs. Allan E.	Board of Trustees
Charles, Mr. Allan E.	
Chatterton, Lynne	Staff
Class, Charles H.	Staff
Cohen, Bernard P.	Sociology
Colby, Kenneth	Psychology
Cole, R. Wade	Staff
Cole, Mrs. R. Wade	
Colman, Ronald	Digital Equipment Corporation
Collins, George A.	Staff

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[*] There were also a few anonymous acceptances.

Concus, Paul	Radiation Laboratory
Connolly, Thomas J.	Aeronautical Engineering
Courson, Merle	First National Bank of San Jose
Crane, George	Lockheed

Denley, Terence W.	Controller's Office
DeWilde, Mrs. Rynhart	Staff
Donio, Jean	Staff
Dornbusch, Sanford M.	Sociology
Duncan, Donald	Office of Naval Research

Eichler, Joseph P.	Eichler Homes
Ellis, Loyd	IBM
Enea, Horace	Staff
Eppert, Ray R.	Burroughs
Estes, William	Institute of Mathematical Studies
Evans, David	U. C. Computation Center

Farnsworth, Paul R.	Psychology
Fein, Louis	Computer Consultant
Fischer, Gay	Staff
Fisher, Don D.	Staff
Fisher, Mrs. Don D.	
Flügge, Wilhelm G.	Engineering Mechanics
Flügge-Lotz, Mrs. Wilhelm G.	Aeronautical Engineering
Forrest, Robert B.	Datamation
Forsythe, Eleanor	Staff
Forsythe, George E.	Staff
Forsythe, Mrs. George E.	
Franklin, Gene F.	Electrical Engineering
Franzini, Joseph B.	Civil Engineering
Fuhrman, Frederick A.	Experimental Medicine

Gere, James M.	School of Engineering
Gibson, Weldon B.	SRI
Gilbarg, David	Mathematics
Gilbert, John P.	Behavioral Science Center
Gilford, Mrs. Dorothy	Office of Naval Research
Given, Homer	IBM
Givens, Wallace	Argonne Labs, Illinois
Glover, Frederic O.	President's Office
Glover, Mrs. Frederic O.	
Gold, Don	Staff
Golub, Gene	Staff
Gordon, Mrs. Norman S.	Staff
Govan, Aileen	Staff
Grad, Arthur	Graduate Division
Gregory, Robert	University of Texas
Gregory, Mrs. Robert	

Hamming, Richard W.	Bell Telephone Laboratories
Hamming, Mrs. Richard W.	
Hansen, R. W.	Burroughs
Harbaugh, John W.	Geology
Herriot, John G.	Staff
Herriot, Mrs. John G.	
Hilton, Ronald	Hispanic-American Studies
Hockney, Roger	Staff
Hockney, Mrs. Roger	
Hollander, Mrs. Myles	Staff
Hosken, Carol	Staff
Hurd, Cuthbert C.	Computer Usage Corporation
Hurley, Mrs. John	Staff
Hwang, Mrs. Richard	Staff
Jackson, Thomas	SEL
Johnson, Reynold	IBM
Junker, Leroy	Staff
Kaplan, Henry S.	Radiology
Kennedy, Robert	Research Administration
Kershner, Gene	Planning Office
Killam, Keith	Pharmacology
Kimmel, Rik	Public School Administrator
Kirk, Cassius	Business Office
Kocher, Bud	IBM
Koenigsberg, Ernest	C.E.I.R.
Kreuder, Norm	Burroughs
Kurtz, Thomas	Dartmouth and staff
Kurtz, Mrs. Thomas	
Lamar, Bob	News and Publications
Langle, Robert J.	Staff
Langle, Mrs. Robert J.	
Larimer, David S.	Dean of Students Office
Larsen, Kenneth	DEC
Lax, Peter	Mathematics and N. Y. University
Lemaitre, C. G.	Visiting Prof. at U.C. from Belgium
Levitt, Michael	Staff
Lewis, Neil	IBM
Lieberman, Gerald	Statistics
Lillick, Ira	Board of Trustees member, lawyer S.F.
Limberg, Phyllis	Staff
Lindstrom, Eugene	IBM
Linsley, Ray K.	Civil Engineering
Linvill, John G.	Electrical Engineering
Listug, William	C.E.I.R.
Littlefield, Mrs. Daniel	Staff
Loftis, John C.	English
Lohrey, Jack	C.E.I.R.
Luke, John	IBM

Markle, Gerald	University of Detroit
Marston, John	Fire Chief
McCarthy, John	Staff
McCarthy, Mrs. John	
McDonough Jr., John R.	Dean of Law School
McGhie, L. Farrell	School of Engineering
McKeeman, William	Staff
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Miller, Jack C.	Pomona College
Moffat, Samuel J.	Medical School Information Officer
Moler, Cleve	Staff
Momyer, Floyd	Radiation Lab, Livermore
Nanney, David Y.	Military Science
Neilsen, I. R.	Pacific Union College
Nyland, Mrs. Robert	Staff
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O'Hagan, Michael	Staff
Ortiz, Julio	Staff
Owens, Robert	National Science Foundation
Panofsky, Wolfgang	SLAC
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Parter, Seymour	Staff
Parter, Mrs. Seymour	
Parzen, Emanuel	Statistics
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Peterson, Allen M.	Electrical Engineering
Pierce, Louis	University of Notre Dame
Poe, B. F.	Burroughs
Polya, George	Mathematics
Polya, Mrs. George	
Pribram, Karl	Psychiatry
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Rosen, Mrs. J. B.	
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Saunders, Diana	Staff
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Shaw, Gordon	Physics
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Smith, Roulette	Staff
Snyder, Rixford K.	Admissions
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Spring, Carl	IBM
Starr, Larry	Staff
Stevenson, Charles	IBM
Street, Robert L.	Civil Engineering
Suppes, Patrick C.	Inst. for Math. Studies in Social Sci.

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Terman, Mrs. Frederick E.	
Terry, Joseph E.	Air Sciences
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Tyson, Royal	Planning Office

Vandergraft, James	Staff
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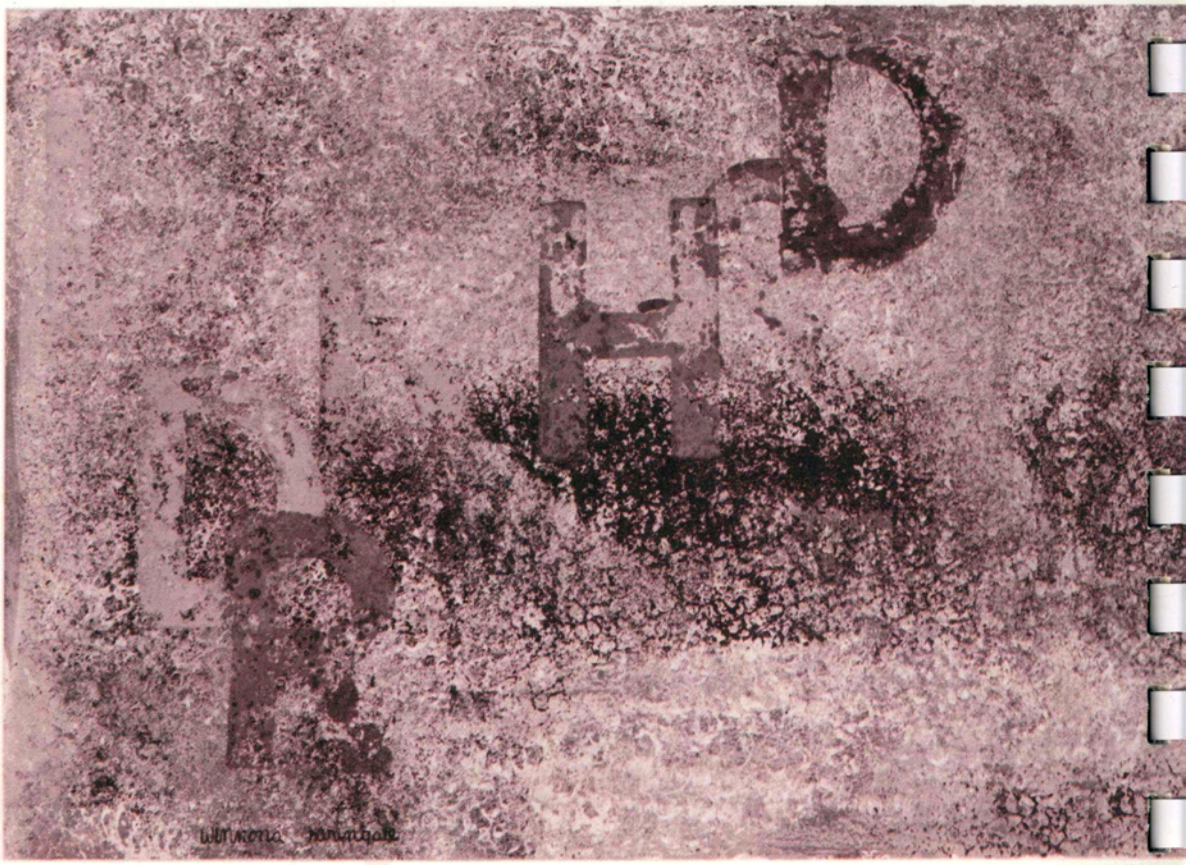
Van Heusen, Mrs. Helen	Early Staff
Van Zoeren, Harold	Staff
Vitale, James	Burroughs (S. F. office)

Wagner, Harvey	Statistics and Economics
Walker, Robert A.	General Studies
Watt, James B.	Staff
Welch, E. G.	Burroughs
Welsch, John H.	Staff
Westover, Douglas	SEL
Widrow, Bernard	Electrical Engineering
Wilbur, Ray	Hewlett Packard
Willis, Arthur	Staff
Wilson, James	Staff
Winters, Peter	
Wise, Lauress L.	School of Engineering
Wohlschag, Donald E.	Biology
Wood, Mrs. Ed	Staff
Wooldridge, Dean	Staff
Zimmerman, F. A.	Pacific Telephone (S. F. office)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