Application of the Burroughs E101 Computer

ALEX ORDEN

THE Burroughs *E101* digital computer is designed to fill the gap between standard desk calculators and large-scale digital computers. The machine combines flexibility of operator access and judgment, as in use of desk calculators, with automaticity on repetitive routines, which is the great virtue of the large-scale digital computers. Use of the machine is expected to be generally on a decentralized basis, in individual offices and laboratories, rather than in a centralized computing machine installation. In many situations decentralizations of computations to the source of the data should more than compensate for the greater internal speed characteristic of large-scale computers.

The *E101* can be used effectively on problems of moderate size in the same automatic fashion as a large-scale digital computer. On the other hand, it can be used as a "super desk calculator," that is, in a manner similar to a desk calculator, but with extension of the operations which can be carried out by the machine, from the basic arithmetic operations, to such operations as square root, trigonometric functions, standard deviation, etc. Finally, the combined approach, the handling of computations in a manner which involves a mixture of manual intervention and automatic sequencing, will be presented in this paper as an approach to computation which warrants a great deal of attention.

The sections which follow present:

1. A brief description of the computer in order to highlight its relation to other machines and provide a basis for the discussion of methods of application. (Literature available from the Burroughs Corporation provides detailed information on characteristics, programming, and operation.)
2. Methods of application of the *E101*, primarily with reference to engineering and scientific computation. The paper is not intended as a review of the general scope of applications, but specific topics are discussed to illustrate the general approach.
3. Business applications.
4. Accessories to the basic machine.

Description of the E101

A prototype of the *E101* is shown in Fig. 1. Seen externally, it is the size of an office desk, has a numeric columnar keyboard input like a standard desk calculator, prints up to 12 digits at a time, at a rate of two words per second (that is, a maximum printing rate of 24 digits per second), and has the computation program stored in pinboards, which are located on the desk top to the right of the keyboard. Internally, the machine contains a magnetic drum of 100 registers, a 3-kw tubeless power supply, and electronic circuitry that involves the use of 163 vacuum tubes and 1,500 diodes.

The most novel construction feature is the pinboard programming unit. This involves, as distinct from most large-scale computers, storage of instructions separately from data. Instructions are, however, expressed in a single-address form of the type which is familiar in the large-scale digital computers, where instructions and data are stored in a single internal memory. For example, the instruction to add the contents of magnetic drum register *29* to the contents of the accumulator is written in the form, +29. Such instructions are entered in the pinboard in the manner shown in Fig. 2. The pinboard has 16 lines, each of which holds one single address instruction. The three characters in +29 require the entry of three pins into a line, and these three pins are indicated by black dots in the top line of the illustration. One pin has been entered in the + column, as shown at the top of the pinboard, one pin in the 2-column in the set of columns that are used for the 10's digit, and one pin in the 9-column in the set of columns that are used for the units digit of the address. Eight such pinboards, each of 16-step capacity, can be mounted in the pinboard panel, giving 128 single-address steps. Transfers to subroutines are handled by instructions such as U 4 12, meaning unconditional transfer to pinboard *4* step 12, as illustrated on a lower line in Fig. 2.

Each of the eight pinboards can be removed and reinserted or replaced easily.

The traditional block diagram for digital computers showing boxes for input, output, memory, arithmetic, and control is familiar to anyone who has dealt with large-scale digital computers; it is shown in Fig. 3 for subsequent comparison with the *E101*. The dashed-line block at the top of Fig. 3, "keyboard input for supervisory control," is usually omitted or considered to be covered by the main input block, but is pertinent here in relation to the *E101*.

This diagram serves well as a functional representation of most general-purpose digital computers. If desired, the input, output, and memory blocks can be shown as several blocks in those machines that contain more than one type of input-output or memory, but the basic character of the schematic remains the same.

By comparison, a functional block diagram for the *E101* is as shown in Fig. 4. The keyboard is the main data input and the printer alone is the output. Coded input-output, shown in dashed lines, will be accessories to the basic machine. The instructions, in the form of pinboards, are indicated as an input because of their removability and interchangeability.

Finally, with regard to the general rela-

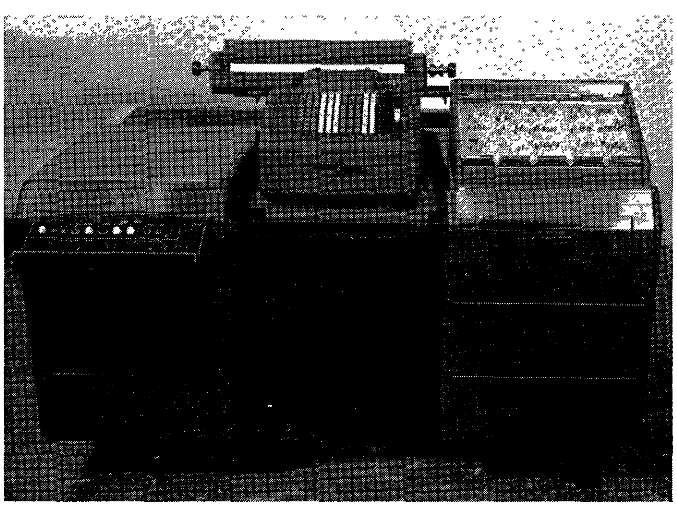

Fig. 1. The E101 digital computer

ALEX ORDEN is with the Burroughs Corporation, Research Center, Paoli, Pa.

tion of the *E101* to other computers, Fig. 5 compares the relative speed and cost of the main existing classes of digital computer. Computers other than the *E101* are divided into four classes: desk calculators; general-purpose punched-card computers such as the International Business Machines Corporation CPC or Remington Rand *409;* magnetic-drum computers; and electronic-memory computers. The majority of the computers under discussion are what is meant here by the magnetic-drum class, while the million-dollar machines with higher-speed memory are what is meant by electronic-memory computers. The computation speed typical of each class and of the *E101*, relative to a desk calculator, is indicated on a logarithmic scale, and above each speed line is a line indicating typical annual operating cost per year including personnel. The need for considering personnel cost, as well as machine cost, is obvious, particularly in the case of the desk calculator where the cost of a machine is minor, but the salary of an operator is, say, $5,000 per year. The indications are that relative to use of desk calculators, the *E101* at a cost increase by a factor of three, can generally increase computation output by a factor of ten. This diagram, no doubt, contains some controversial figures, but they are presented here only as the author's general estimates for the sake of perspective on the *E101*.

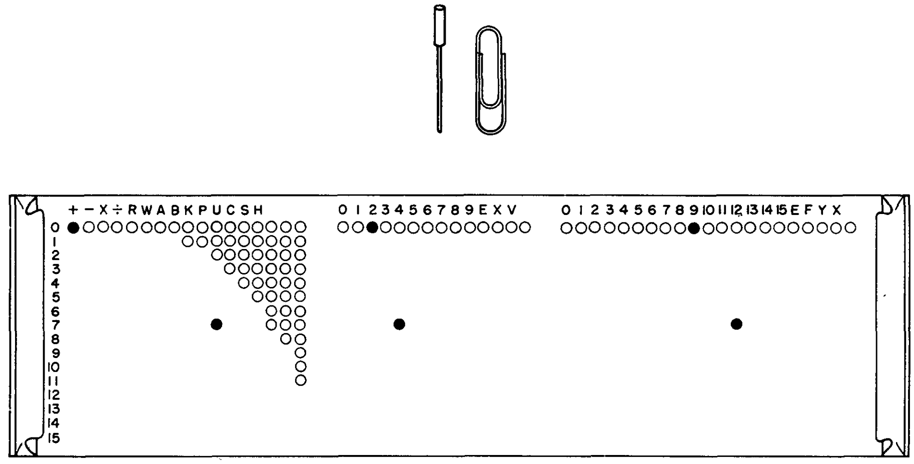

Fig. 2. E101 pinboard

Methods of Application

Burroughs literature on the *E101* has stressed the point that the *E101* bridges the gap between large-scale digital computers on the one hand and use of ordinary desk calculators on the other. The main objective of this paper is to explain what is implied here by "bridging the gap."

A first, but rather negative way of explaining what is meant by the phrase has been implicit in some of the foregoing remarks. It was suggested that the general-purpose computers which center in a magnetic drum, and which are called "small computers," are functionally identical with the large computers. It is not common to speak of these magnetic-drum machines as bridging the gap between desk calculators and large digital computers. Of course, they do tend to bridge the gap in terms of cost, but in terms of method of operation and application they are practically the same as the large computers.

The *E101*, as a machine with direct keyboard input and considerable emphasis on operator participation in the computations does, at least, have more of a gap-bridging character between desk calculators and large computers than the general class of magnetic-drum machines. Incidentally, such remarks are not intended to discount the importance of the general type of magnetic-drum machines. On the contrary, that class of machine is clearly of great importance in the computer field.

The foregoing approach, a negative one, was to suggest that other moderate-speed computers do not fill the gap functionally between desk calculators and large computers but that the *E101* does. For an explanation on the positive side, one can start by raising the question: What would be the proper approach in bridging the gap between automatic and hand computations? An initial answer to that might well be to build a machine that would permit either method of operation. Of course, if such a machine were to overemphasize either side, the automatic or the manual, its use would tend to drift over to that side, and the machine would not bridge the gap.

The *E101* does provide both methods of computation, automatic as in a large-scale computer, and manual as in the use of a desk calculator. The real question will be: Why are both needed in a single machine? But before proceeding to that, the application of the computer, first as an automatic machine, and second as a manual machine, will be described.

As an automatic machine, the *E101* functions in the same way as any of the general-purpose computers, except that in the basic model the data are entered directly through a keyboard rather than by some form of recording. In other words, once the data are entered, the machine proceeds entirely automatically. The size of technical computation problem for which the machine is suitable for automatic processing can be gauged by the following two examples.

1. Solution of systems of differential equations whose complexity can go up to the general level of the equations shown in the

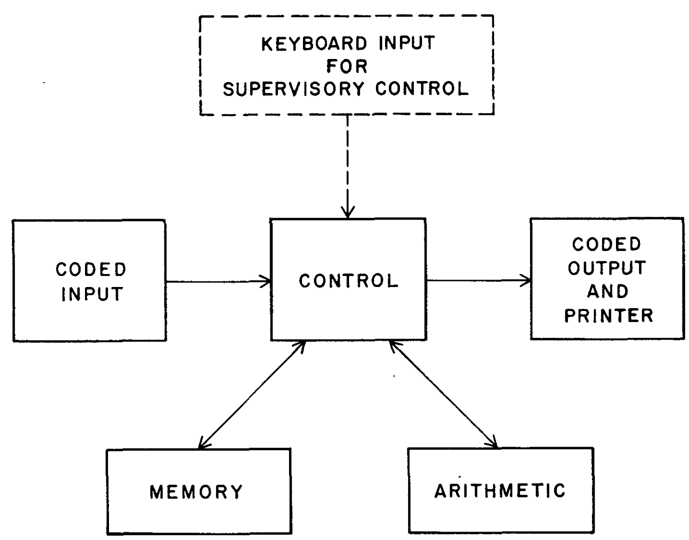

Fig. 3. Traditional digital computer block diagram

following. For this system of equations, the machine would automatically print a set of values of the unknowns and their first derivatives at successive discrete time values at the rate of one set of values every 25 seconds. Differential equations up to this level of complexity are, of course, adequate for many classical aspects of engineering, chemistry, and physics, but are not adequate for the complete solution of guided-missile and aircraft-motion problems. Differential equation suitable for the *E101* are

$$\ddot{x}-2y=x-(1-\mu)\frac{x-x_1}{r_1^3}-\mu\frac{x-x_2}{r_2^3}$$

$$\ddot{y}-2\dot{x}=y-(1-\mu)\frac{y}{r_1^3}-\mu\frac{y}{r_2^3}$$

$$\ddot{z}=-(1-\mu)\frac{z}{r_1^3}-\mu\frac{z}{r_2^3}$$

$$r_1=\sqrt{(x-x_1)^2+y^2+z^2}$$

$$r=\sqrt{(x-x_2)^2+y^2+z^2}$$

x_1, x_2, and μ are constants

2. A typical data reduction problem that the *E101* could handle automatically in the same manner as any other digital computer, except for data insertion, is shown in Fig. 7. This problem is the data reduction involved in wind-tunnel testing of aircraft models. Each set of data would be run on the *E101* in about 2 minutes.

Input Data: $\delta_1 \ldots \delta_6$, α^1, ρ, M, ψ
Printed Results: $(C_Y)_3$, $(C_L)_4$, $(C_L)_5$, α_6, $(C_D)_6$, $(C_M)_6$, $(C_N)_3$

Balance Interaction

$\overline{NF}_1=a_1\delta_1+a_2\delta_2+a_3\delta_3+a_4\delta_4+a_5\delta_5+a_6\delta_6$
$\overline{AF}_1=b_1\delta_1+b_2\delta_2+\ldots \quad +b_6\delta_6$
$Y_1=c_1\delta_1+\ldots \quad +c_6\delta_6$
$L_1=d_1\delta_1+\ldots \quad +d_6\delta_6$
$M_1=e_1\delta_1+\ldots \quad +e_6\delta_6$
$N_1=f_1\delta_1+\ldots \quad +f_6\delta_6$

Tares

$\overline{NF}_2=\overline{NF}_1+(1-\cos\alpha^1)W$
$\overline{AF}_2=\overline{AF}_1+W\sin\alpha^1$
$M_2=M_1-(1-\cos\alpha^1)Wl_1+\overline{NF}_2l_2$
$N_2=N_1+Y_1l_3$
$q=(\gamma/2)\rho M_2$

Coefficients

$(C_{NF})_3=\overline{NF}_2/qs \qquad (C_L)_3=\dfrac{L_1}{qsb}$
$(C_{AF})_3=\overline{AF}_2/qs \qquad (C_M)_3=M_2/qsc$
$(C_Y)_3=Y_1/qs \qquad (C_N)_3=N_2/qsb$

Body Axes to Wind Axes

$(C_x)_4=(C_{AF})_3\cos\alpha^1+(C_{NF})_3\sin\alpha^1$
$(C_z)_4=(C_{NF})_3\cos\alpha^1-(C_{AF})_3\sin\alpha^1$
$(C_L)_4=(C_L)_3\cos\alpha^1+(C_N)_3\sin\alpha^1$

Wind Axes to Stability Axes

$(C_L)_5=-(C_z)_4$
$(C_D)_5=-(C_x)_4\cos\psi+(C_Y)_3\sin\psi$

Tunnel Wall Effects

$\alpha_6=\alpha^1+K_1(C_L)_5$
$(C_D)_6=(C_D)_5+K_2(C_L{}^2)_5+\sin\beta(C_L)_5+K_3$
$(C_M)_6=(C_M)_3+K_4(C_L)_5$

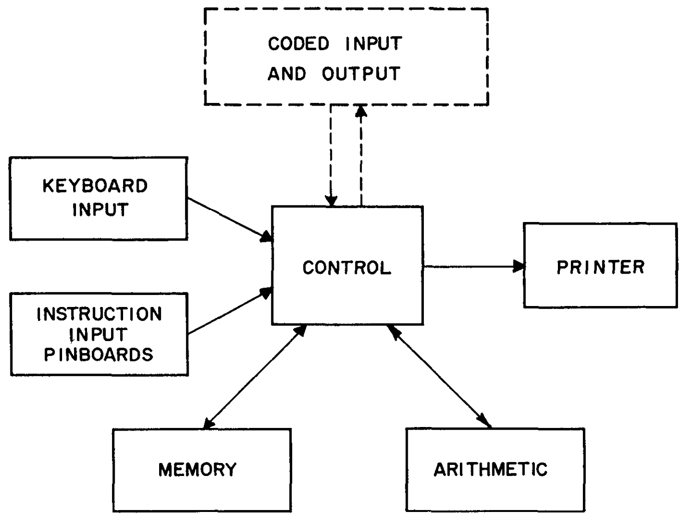

Fig. 4. E101 functional block diagram

The purpose of these examples is to indicate up to what level of complexity the *E101* permits automatic solution. The problems indicated are moderately complex, and indicate coverage of an appreciable fraction of the computation problems that arise in engineering. Larger problems are, of course, fairly plentiful, and on the *E101* would require breaking the computations up into several pieces to be handled separately.

Turning to use of the *E101* as a manual computer, it's so designed that it can operate effectively in a manner which might be called the super desk calculator. The pinboards can be set up in general-purpose form for providing such operations as square root, tangent, logarithms, product or quotient of complex numbers, cross product of vectors, and so on. After entry of the numbers in the keyboard, touching one of the so-called "special start buttons" would cause the machine to carry out the desired operations and print the results. Used in this fashion, the machine would be considerably more powerful than a desk calculator, but the main program of computations would be determined entirely by the operator.

Now, why bridge the gap between the automatic and manual approaches? This is the basic question toward which this paper is directed.

There is a large amount of technical computation in which two factors are present:

1. The need for engineering judgment during the computations.
2. A large volume of computational drudgery.

The use of desk calculators allows the operator to use his judgment at every step, but does not take care of the drudgery. The use of large-scale computers, or the small computers modeled after them, eliminates the drudgery but does not provide for the use of judgment. Despite the fact that general-purpose computers are programmed to branch out into a number of alternative computational subroutines, it is not correct to say that any appreciable amount of judgment has been programmed into the computations. The choices made automatically during the computation are essentially routine, and are more accurately described as automatic housekeeping than as judgment. Basically, the program for a given problem on a digital computer is a large mechanized subroutine in a problem in which the main program is not mechanized at all.

The solution of engineering-design problems on large digital computers is likely to involve automatic computation in order to provide performance characteristics of some device or structure many of whose design parameters can be varied. A thoroughly normal situation might be that there are ten design parameters to be studied and that it would be nice to try ten values for each of these parameters. This means 10^{10} cases to be computed. If a large digital computer could run through each case in 5 seconds, it would take about 1,600 years to do the 10^{10} computations, all, of course, without human intervention, except for machine maintenance.

There is a gap, then, between large computers that offer elimination of computation drudgery, but no human intervention for use of judgment, and desk calculators that allow judgment at every step but leave in all the drudgery. The design of the *E101* is based on the opinion that this gap is not a vague no-man's land for the computer field, but rather, that the target is clear-cut: to provide a machine which

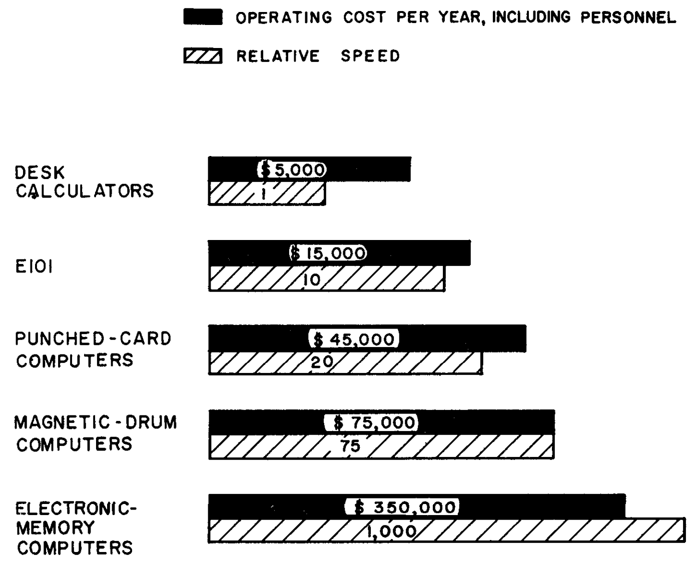

Fig. 5. Classes of digital computers

permits easy access to a variety of routines, while leaving judgment as to the course of the computation in human hands. The routines needed for a specific problem can, of course, be special ones, programmed for that problem, rather than general-purpose operations, such as square root, logarithms, etc., which were discussed earlier. As a first attack on this target, the *E101* offers easy access to routines of relatively small or moderate complexity.

The central objective in the *E101*, then, is to provide maximum simplicity in access to a variety of routines. The main ways in which the design meets this objective are:

1. The first stage of access is getting routines programmed and debugged. As indicated earlier in this paper in the description of pinboard programming, the program is in a very straight-forward language, and is entered on pinboards in a form which is practically as simple as writing instructions down on paper. In debugging routines, the pinboards can be inserted in the machine and run through step by step, with print-out at any step desired. If any error is found in the program, it is usually a matter of changing a few pin positions to correct the trouble The routine is then ready for use.

2. Access to any routine during a computation is as follows: If the pinboard panels have sufficient capacity for all of the routines required, access to any one of them can be obtained by touching a control button. If additional routines are required, pinboards can be replaced easily. Of course, if the character or size of the problem is such that pinboard replacements would have to be very frequent, the procedure becomes awkward and probably unsatisfactory.

3. The data for alternative routines can be entered directly in a keyboard that has the features normally associated with a keyboard calculator.

A reasonably careful presentation of a problem in which the *E101* would be used to good effect along the lines under discussion would require considerable detail, and is consequently not included here. A partial illustration will be given by discussing a standard problem, the solution of sets of simultaneous linear equations.

The *E101* with 100 words of memory in the base model appears at first to be limited to nine equations in nine unknowns, which would involve storage of 81 coefficients in the equations and nine numbers on the right-hand side of the equations. However, even in large computers with 1,000 words or more of fast memory, the solution of large systems of equations is often handled by breaking the set of coefficients into small square blocks, that is, in mathematical terms, by partitioning of matrices. In a well-known UNIVAC code, for example, the coefficients are handled in 10 by 10 blocks, regardless of the number of equations to be solved. The interrelation between blocks of data in a large computer is programmed so that interrelations in the handling of successive blocks is carried out automatically, but this requires a good deal of programming. With the *E101* one can work with 9 by 9 blocks and have the operator guide the combining and sequencing of the blocks. The amount of coding for the *E101* is probably about one-third of that for a large computer, while the basic drudgery of the computation is still essentially taken care of by the machine. This simple example does not illustrate a case in which judgment is required during the computation, but it does indicate how a substantial amount of programming for a large computer can be replaced by a small amount of human guidance of the computations.

Business Applications

The computer-design philosophy discussed applies, in a broad way, to engineering computation. The greatest impact of the *E101* in business computation is likely to be in analytical aspects of cost accounting, and in related business analyses such as those of operations research. In the latter case, the general approach to management problems is often similar to the methods of science and engineering.

Some specific cases of straightforward business applications which have been analyzed for the *E101* involve cost analysis, tax assessment, sales quotas, and parts ordering for manufacturing.

As is well known to those who have been analyzing the use of digital computers in business applications, it is as yet very difficult to make any broad generalizations. Although the *E101* is not expected to apply in all types of business computation, it is expected that it will be very effective in certain areas. The underlying design philosophy on this point is simple: If the shoe fits, wear it. Some characteristics of the basic machine, such as having form facilities that are as good as any standard accounting machine, and some accessories which will be provided, will help make the shoe fit on some of the potential applications.

Accessories to the Basic Machine

The parameters of the basic machine as described and discussed appear to be a sound approach to the basic objective, but in order to encompass a larger realm of application, the *E101* will be offered with certain optional accessories. The first of these accessories to be made available is a punched-tape reader. This reader will have two functions: first, of course, for automatic entry of numeric data; second, as a source of instructions to supplement the pinboards. The basic machine has eight pinboards, each of 16-step capacity. Addition of punched tape, in the form of a closed loop, may be considered as providing a ninth pinboard, which is somewhat slower in operation, but has the virtue of being of unlimited capacity. In adding instructions from tape, the ease of access to computational routines has been preserved. The coding is the same as for the pinboards, the tape can be inserted or replaced easily, and the instructions on the tape are used directly by the machine, that is, they do not first have to be transferred to an internal memory.

Discussion

J. H. Howard (Chairman): I might ask one question. I don't think you mentioned how programs could be stored on the template. Do you want to mention that?

Alex Orden: The program is stored in the pinboards which are removable and can be set on a shelf. In addition, as perhaps was clear from the illustration of the pinboard, we provide templates which are simply cards of the same size as the pinboard itself, with all the same numerals on them indicating what the instructions are and what line of coding you are in.

The general mode of programming a problem is to circle holes on a template and then bring the template over to the machine, take a pinboard, and drop pins in where the holes have been circled. Then generally the paper template is left on the pinboard more or less permanently. If the program is going to be used very often, the pinboards are stored on a shelf. If the program is going to be used intermittently, the set of paper templates, say half a dozen of them, can be removed as the pins are dropped out and the templates can be stored in an envelope. Reloading the program onto a set of pinboards at some later date requires some 3 to 5 minutes to load up a set of boards.

C. Gotlieb (Computation Centre, University of Toronto): Could you briefly list the order code available?

Alex Orden: The order code is more or less conventional for a small digital computer, i.e., the same general approach as in a large computer, but a less elaborate repertoire of instructions. The machine has the usual arithmetic instructions, shift instructions, read-in from keyboard, and print-out, as well as conditional and unconditional transfers and a special stepping instruction which allows you to scan through a sequence of addresses in programming loops, which involves the changing of addresses as part of a sequence of instructions.

There are some refinements. For example, absolute value instructions are included. There are also refinements in printing control that enter from the versatility of the accounting-machine-type printing unit, such as four separate types of print command which control format.

Mr. Casey (General Electric Company): Can you give us some figures on the time of various instructions? Has this machine been applied to solution of differential equations by relaxation methods?

Alex Orden: The basic speed was indicated when I said that the machine is generally in the range of 10 to 20 times faster than the use of a desk calculator. The addition-type operations (addition, subtraction, shift, take-absolute-value, and a few others) is $^1/_{20}$ second for each. Multiplication and division are $^1/_4$ second each. Print is half a second for a full word of up to 12 digits and sign.

As far as solution of differential equations by relaxation methods is concerned, I presume you mean the solution of partial differential equations, or at least that is uppermost in my mind.

That happens to be a field in which people speak very highly of the use of judgment and the use of an ordinary desk calculator. One takes a network of points and relaxes by hopping around from point to point, using one's best judgment, or at least using a visual scan which is to a certain extent more efficient than an automatic computer scan to find the largest residual to relax on.

We have been planning to study the use of the *E 101* on this type of problem from the point of view of the "super desk calculator." That is, the machine would be programmed to provide a few specialized routines so that when you have to do something computationally, you enter a number or several numbers and then the machine does the rest, rather than handle the computation fully automatically as you would in a large-scale computer.

My impression is that this will be a good approach in relaxation problems where you have nonrectilinear co-ordinates, that is, in cylindrical or spherical coordinates, where the computational drudgery associated with doing relaxation by hand with a desk calculator gets aggravating. I am doubtful whether it would be worth while to handle rectilinear co-ordinate problems this way.

J. R. Anderson (Bell Telephone Laboratories): Will the pinboard be available as a separate article of commerce?

Alex Orden: The pinboards will be available as an item to be purchased separately. Two full sets of pinboards will be provided with the machine.

D. N. Lee: Can you explain how storage of information is accomplished by the pinboard?

Alex Orden: Each pin makes a connection in a rectangular grid switching matrix. Each line of pin holes is for one single address instruction. Generally, three pins are inserted in a line, one pin to select the type of instruction, one for the tens digit of the address, and one for the units digit. The switching through a succession of pinboard steps is by electromechanical means.

J. Kates (KCS Data Control, Ltd.): Would you break down the $15,000 annual cost? What is the word length and storage capacity?

John Mekota (Raytheon Manufacturing Company): What is the cost of a pinboard? What are the operational speeds?

K. Enslein (University of Rochester): Does this computer also bridge the cost gap? How much for the basic machine?

Alex Orden: Let me begin with the last question, "Does this computer bridge the cost gap and what is the cost of the basic machine?" The machine price is $32,500. The rental price is $850 a month, or about $10,000 a year. We assert that this is a bridging of the gap costwise since this machine can be associated with a small group in a laboratory having one general type of problem and one person would be enough to program and operate this machine.

Of course the time spent on programming and operation might be spread over several men and be the equivalent of one full-time person, so that the rental cost is $10,000 a year, roughly, plus $5,000 a year for an operator. If you are talking about engineers, let us say it is $7,000 or $8,000 for operation. This is about double or triple the cost of having people work at desk calculators where the primary cost is salary. I think that is a bridging of the cost gap.

The price of extra pinboards has not been set yet. The operation speeds were discussed earlier, and I have broken down the $15,000 annual cost. The word length is 12 decimal digits internally and sign.

The average speed is the result of a combination of factors, such as keyboard entry, stepping of instructions, and the electronic mode of internal operation. I like to think of the machine as well balanced internally because if you try to come to grips with ways to speed up the machine then you find that no one way of changing things will alter the speed of solving problems greatly.

H. Freeman (Sperry Gyroscope Company): Could you give an indication of the complexity of the machine, say by giving the number of tubes, diodes, or relays?

Alex Orden. There are about 160 vacuum tubes and about 1,500 diodes. I am not certain of the number of relays. I believe it is something of the order of 20.

W. A. Hosier (Lincoln Laboratory, Massachusetts Institute of Techology): Do you have any reliability figures on the *E 101*, and what type of maintenance is felt necessary?

Alex Orden: We have operated only the model which is here at this conference. A second model is nearly complete with some of the features that will be on the production model, and the first production units will be on test within several months.

The reliability of our present initial model is a little hard to say very much about because, as usual, this is a machine that has gone through engineering tests, engineering modification, training of maintenance people, and all the usual headaches of a first machine.

The machine has been very nice to us in the sense of rising to practically every critical occasion. It has been on the road four times. This is the fourth, and each time it has been moved somewhere, set up, and put into operation. Of course in the framework of a meeting in a hotel whether it has been in operation with 100-per-cent accuracy, I do not know and nobody else knows.

As for type of maintenance, Burroughs will offer the machine by rental, meaning full maintenance, and by purchase, in which case the first year of maintenance will be part of the purchase price.

As far as training of your own maintenance people is concerned, the machine has the complexities that are usually associated with digital computers. On the other hand, it is a smaller machine with fewer tubes and fewer circuits, so that it certainly should be an easier task to train maintenance men for this machine than for the larger machines.