JIA 79 (1953) 0274-0322

LARGE-SCALE ELECTRONIC DIGITAL COMPUTING MACHINES

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[Submitted to the Institute, 27 April 1953]

INTRODUCTION

IN a paper(1) read before the Institute in January 1936, E. W. Phillips discussed developments in computing machines and made the following prediction:

If it [the light-ray machine] is provided with all the necessary material on the morning of 1st January, the whole of the valuation will be completed within 15 minutes or so. Indeed when the actuary arrives there will still be time to complete the valuation over again on eight or nine other bases before he goes out to lunch, and yet have ready the figures necessary for the Annual General Meeting in the afternoon.

2. It is unlikely that anyone who heard Phillips's paper in 1936 expected that a machine capable of fulfilling his prediction would exist within ten years. This startling materialization occurred before 1946 but remained a military secret until the summer of that year, when ENIAC (Electronic Numerical Integrator and Computer) was shown to the public in the Moore School of Electrical Engineering at the University of Pennsylvania where it had been constructed.

3. Since the construction of ENIAC several Large Scale Electronic Digital Computers have been built in the U.S.A. In Britain machines have been sponsored by Universities and Government or Industrial Research Organizations for use on mathematical work and by at least one large manufacturing and distributing commercial organization. The four British machines which have received most notice are:

ACE (Automatic Computing Engine) at the National Physical Laboratory is officially regarded as a small-scale model of a computer but has been used on many practical problems;

EDSAC (Electronic Delay Storage Automatic Calculator) at Cambridge Mathematical Laboratory has been in continuous use since 1949;

LEO (Lyons Electronic Office) at J. Lyons and Co., Ltd., Cadby Hall, has been in use since early 1951 and plans exist for it to take over a large amount of clerical work;

Manchester University Digital Computer Mark II at Manchester University has been in use since July 1951.

4. The object of this paper, which attempts no more than a general introduction to these new aids to calculation and processing records, is to serve as a preliminary to the detailed study which it is believed many actuaries will need to make in the near future.

5. A further object in stimulating the interest of members of the Institute in this subject is to encourage a statement of actuarial requirements whilst there is time to influence design and future research.

6. In this country we can benefit from the studies made by our professional brethren in North America where actuaries have been investigating the use of electronic computers for some two years or more. Reports and discussions by a committee appointed by the Society of Actuaries are given in papers 2, 3 and 4 of the references. Extracts are quoted from these papers, and the author gladly takes this opportunity of acknowledging the assistance he has received from Mr Malvin E. Davis, chairman of the committee, and Mr John J. Finelli.

7. Section I is an attempt to disperse some of the clouds of black magic surrounding the subject by explaining in non-technical language these extremely technical objects. The author believes that it is possible to get the best out of a calculating machine only when the user possesses some knowledge of the way in which it works. Such a knowledge also allows potential users to assess what may appear to be extravagant claims made by enthusiasts. Those who find even the mild technicalities in section I not to their liking should at least turn to the summary in § 54 and § 55.

8. Section II includes an example of a programme of instructions for an actuarial calculation.

9. Sections III, IV and V discuss the speed, reliability and use of a computer in a life office. Section VI is a short summary.

10. It is neither desirable nor possible in a paper of this kind to cover all the variations in design in existing computers, nor to mention the devices under development in various laboratories. The information should be regarded as a general outline of principles as they are appreciated today in this rapidly developing field and not as an accurate specification of any computer or device.

11. The word 'electronic' in the title limits the scope of the paper to computers relying largely on the properties of thermionic valves familiar in appearance to anyone who has seen the inside of a radio set. However, it should be said that all the functions of electronic computers may be realized, though at lower speeds, by relay or other electro-mechanical devices.

12. The word 'digital' excludes analogue machines; recent advances in these are described in Hartree (5).

13. The implication of 'large scale' raises a subject on which different opinions may be held. The words are used in the title to exclude from consideration machines which use electronic devices merely to realize isolated processes already possible by other methods.

14. Much of the information contained in this paper is drawn from ERA (6), Hartree (5) and Berkeley (7). The author must also acknowledge the help he has received from designers of various machines who have not hesitated to expend their energies in giving demonstrations and explanations in simple terms. In particular, such assistance has been obtained from Prof. Howard M. Aiken, Director of the Computation Laboratory, Harvard University, and Dr M. V. Wilkes, Director of the University Mathematical Laboratory, Cambridge.

I. FUNCTIONAL DESCRIPTION

15. Because the following description of these assemblies of electrical components avoids technicalities the reader is asked to accept, as an act of faith, the existence of devices with the stated properties.

Valves and numbers

16. The fundamental component is the thermionic valve. Because it functions invisibly, inaudibly and usually odourlessly, there is an aura of mystery about it. For the purposes of this paper it is sufficient to regard a valve as an electrically operated electric switch, functionally equivalent to a common wall switch the knob of which is imagined to change position when an electric current is fed to it. The property which distinguishes a valve from a relay, which is an older form of an electrically operated switch, is that it can change from the OFF to the ON position and back again as frequently as a million times a second. The valve can do this because the change takes place without any mechanical movement.

17. When connected with certain other components a valve can cause an electric wire to carry at regular intervals of time momentary charges of electricity or, as we shall call them, 'pulses'. This is an effect similar to that of inducing, by mechanical means, 9 pulses in a wire when a 9 is dialled on a telephone.

18. These pulses may represent numbers in various ways. The simplest and only way we shall consider here is a pure binary representation, in which the digits 1 and 0 are represented by the presence and absence of a pulse. (An elementary explanation of the binary scale of notation is given in Michaelson (8).) The digital position or power of two is related to the time scale, thus the presence of a pulse in the nth time interval represents 2^{n-1}. The first pulse therefore represents the least significant digit. A maximum value, say 32 to fix ideas, is selected for n so that after every 32 pulses a new number is started. It is convenient to call the time for our standard length number, in this case 32 pulses, to pass through a wire a 'minor cycle' and to denote the pulses, which differ only in the time of their occurrence, by P_1, P_2, ..., P_{32}.

19. The reason for the high speed of these computers is now apparent. With a frequency of 100,000 pulses a second, which is far below the maximum possible, any denary integer from 0 to $2^{32}-1=4,294,967,295$ may be transmitted from one device to another in a minor cycle or ·00032 seconds. For example the denary number 39 = binary 100111 would be represented by the presence of P_1, P_2, P_3, P_6 and the absence of all other pulses. Hereafter the word 'number' may refer either to the number or its pulse representation, an ambiguity not expected to confuse.

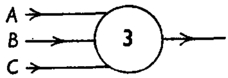
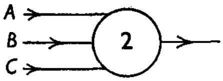
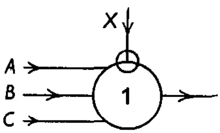
20. Electronic computers achieve their results by processing these pulses in an ordered manner which simulates an arithmetical operation. The function of most of the devices inside a computer can be defined in terms of the conditions necessary on its input lines to cause any pulse, P_i, to occur on its output lines.

An adding circuit

21. For example, the rules for the addition of three binary digits are simple: $0+0+0=0$; $0+0+1=1$; $0+1+1=0$ and carry 1; $1+1+1=1$ and

carry 1. As an illustration of a typical electronic method an adding circuit will be described in some detail.

22. We must accept the availability of the following devices which are in fact assemblies of valves and other electronic hardware.*

Symbol	Property
	P_i emerges on the output line only if P_i occurs on all three input lines.
	P_i emerges on the output line if P_i occurs on any two or all three input lines.
	P_i emerges on the output line only if both the following conditions are satisfied—(1) P_i occurs on one or more of the input lines A, B or C: (2) P_i does not occur on the inhibiting line X.
	P_i emerges on the output line only if P_{i-1} occurred on the input line.

23. Fig. 1 shows the above devices connected together in such a way that if two numbers enter on lines A and B in the same minor cycle then their sum will emerge on line S.

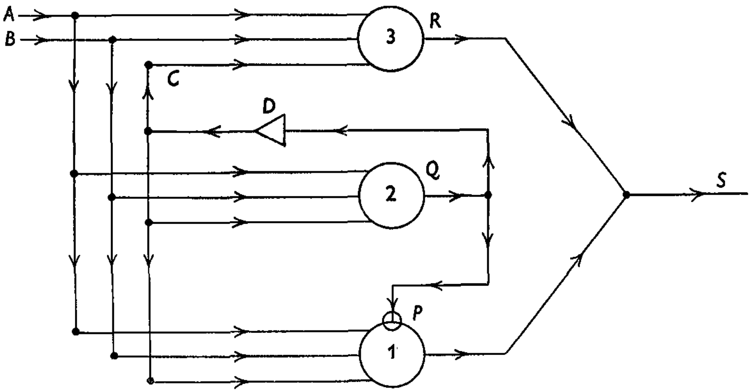


Fig. 1. An adding circuit.

* Hardware is the generally accepted colloquialism for anything inside a computer other than an engineer.

24. After P_1 there are 8 possible pulse conditions on the two input lines A and B and the delay carry digit line C. For example if, in the time interval i, $A, B, C = 1, 1, 0$, then:

R receives P_i on 2 lines and does not emit a P_i,
Q receives P_i on 2 lines and emits P_i to D and P,
P receives P_i from Q on the inhibiting line and does not emit a P_i.

Therefore S does not carry a P_i and at time $i+1$, D will emit a P_{i+1}, together representing $1+1+0=10$.
To prevent a carry spilling over to another number, the pulse delay unit D does not operate in the 32nd time interval.

25. Subtraction can be achieved by directing the subtrahend through a 'Notter'. This charmingly named device has the property of emitting P_i only if P_i is not entered into it. The output of a Notter is therefore the 1's complement of the input, permitting subtraction to be performed in a manner similar to the familiar use of 9's complements in punched-card tabulators.

26. Since the passage of both numbers through the circuit is simultaneous, an addition or subtraction takes place in a minor cycle.

27. Multiplication and division can be carried out by similar methods, the simplest of which is, perhaps, repeated addition or subtraction. The time taken for these operations is usually longer than one minor cycle; multiplication, for example, is completed in many computers in a time of the order of one minor cycle for each binary digit in the multiplier.

Storage

28. It is of course not sufficient to be able to perform the four basic arithmetical operations on numbers which are merely ephemeral pulse trains. Some means must be found to retain the numbers and bring them into circulation when required. The devices performing these functions will here be called 'Storage Units' in preference to the anthropological term 'Memory', use of which encourages misguided elevation of these machines to electronic 'brains' with the implication that they are something more than mere man-made and man-controlled calculating aids differing only in speed and capacity from older aids.

29. Remembering that we are regarding a valve as a switch that can be set to a particular state by a pulse, we can see that the two binary digits may be represented by the two states of a valve. In one state the valve is said to be conducting, in the other non-conducting.

30. A 32-digit number may then be stored in 32 valves by setting the ith valve to a conducting state only if P_i were present in the number. The stored number may be regained by subsequently causing each valve in turn to emit its P_i only if it is in the conducting state.

31. Valve-storage is comparatively expensive and is now used almost exclusively where, in addition to retaining the number, it is required that the value of the number should cause switches in other devices to be held in an ON position for an appreciable length of time. This requirement is the basic property of the important Control Unit which gives computers their high degree of automaticity; it is more fully considered later.

32. The following methods are examples of large-capacity stores in current use:

(*a*) Supersonic Delay Lines, in which a number moving at the speed of sound is continuously recirculated. In EDSAC are delay lines with a total storage capacity of 16,800 binary digits.

(*b*) Magnetic Drums, on the rotating surface of which a number is represented by the magnetization or non-magnetization of adjacent areas. In the Manchester machine is a drum with a capacity of 600,000 binary digits. Two advantages of this form of storage are that its contents do not disappear when the power supply is switched off and that it is relatively cheap. It suffers from slow access time because the period for the drum to rotate to the position at which a required number may be read is long compared with the operating times of the other devices.

(*c*) Cathode-Ray Tubes, on the surface of which a number is represented by the presence or absence of dot images. This is a form of storage to which numbers may be sent or from which numbers may be read with much greater speed than is the case with the other two forms. In the Manchester machine are 8 tubes each with a capacity of 1280 binary digits, the general theory of operation being to transfer numbers from the large-capacity but slow drum to the tubes immediately before they are required.

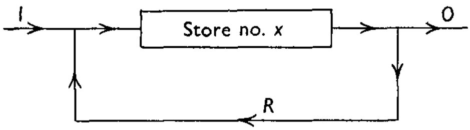


Fig. 2. Storage Unit.

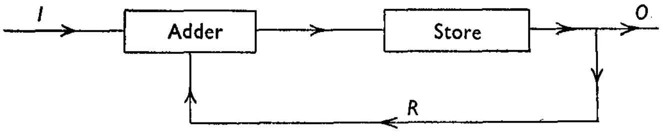


Fig. 3. Accumulator.

33. Fig. 2 shows the logic of a delay line. The length of the line is such that a pulse entering on line I in the ith time interval of the mth minor cycle will emerge on the line O in the ith interval of the $(m+1)$th minor cycle. Since the pulse also travels down the line R to be re-entered on the line I it becomes available on the line O in all minor cycles subsequent to the mth. Circuitry is provided to arrange the erasure of any previous contents when a new number is sent in on the line I.

34. Different Storage Positions within the whole Storage Unit are distinguished by numbers. The capacity of a Storage Position is usually that of one standard length number, in our example 32 binary digits.

Accumulators

35. We can now consider an Accumulator which is an assembly of the adding circuit in Fig. 1 and a Storage Unit. Linked in the way shown in Fig. 3 they produce a device with the same functions as the adding register in a desk calculating machine.

36. The box labelled 'Adder' stands for all the circuitry in Fig. 1; hence the implied function of this box is to add a new number entering on line I to the previous contents of the store which are circulating on R. The simplified symbols for Storage Units and Adders shown in Figs. 4*a* and 4*b* will be used hereafter.

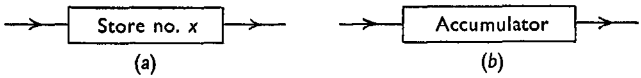


Fig. 4. Simplified symbols.

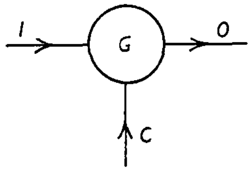


Fig. 5. Gate.

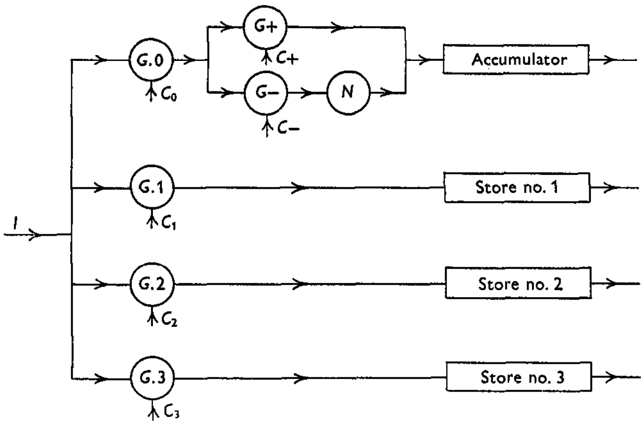


Fig. 6. Gate Circuit.

37. In order to specify the source and destination of the numbers involved in any operation we must introduce one further device. It is called a 'Gate' and is shown in Fig. 5. The property of a Gate is similar to the devices in the adding circuit of Fig. 1. The line O will be pulsed only if the two input lines I and C are simultaneously pulsed.

38. An example of the use of Gates is shown in Fig. 6 where a number entering on I is directed to an Accumulator (positively or in complement) or one of three Storage Positions.

39. We assume that during a minor cycle we have the ability to pulse any one of the Gates 0 to 3 along its C line with all P_i from 1 to 32; the Gate so

pulsed is then said to be open. The number entering on I will fail to pass the shut Gates because only the single opened Gate supplies a P_i on its C line to match any P_i in the number. Similarly the opening of one of the Gates, $G+$ or $G-$, defines whether a number allowed into the Accumulator by $G.0$ is added to or subtracted from the previous contents; if $G-$ is opened, the number is complemented by passing through the Notter (N).

Interrelation of the devices

40. Input and output mechanisms to communicate with the outside world are necessary. Punched cards and punched paper tape are in use; output in printed form typed by a teleprinter or electric typewriter is also popular. All these mechanisms operate at slower basic speeds than the electronic internal devices and much current research effort is devoted to finding faster input and output means.

41. The interrelation of the equipment so far described is shown in the somewhat idealized diagram of Fig. 7; the Accumulator and some arithmetical devices which have received scant mention are included in the block 'Arithmetic Unit'.

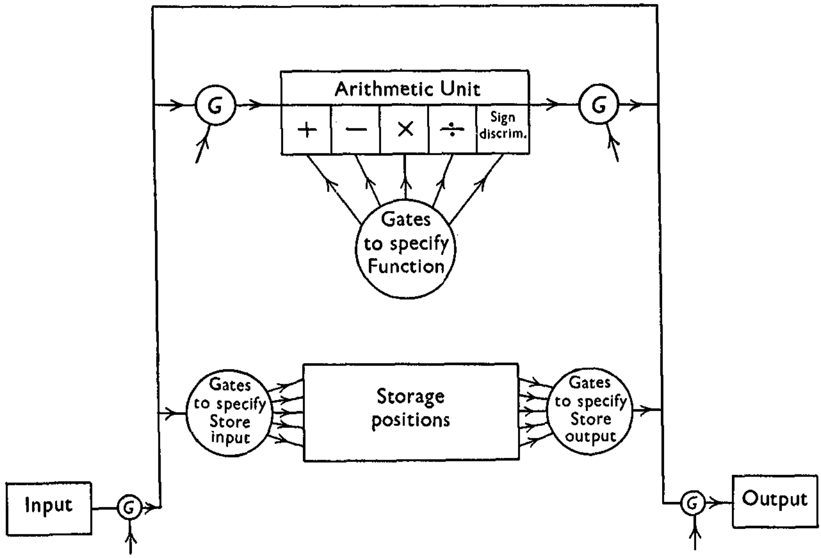


Fig. 7. Basic computer assembly.

42. Any calculation expressible as a sequence of arithmetical operations performed on operands stored in the machine, or available at the input, may be carried out in a series of minor cycles by such an assembly.

Control Unit

43. It is necessary to arrange that the appropriate Gates should be open during each minor cycle. This important function is carried out by the Control Unit.

44. The simplest form of Control Unit would be a panel of manually operated switches, one for each Gate, to be set between each minor cycle, and a push button to call in the execution of a minor cycle. Such a method would be absurdly out of balance, since the time to set the switches would be measured in seconds against 1/10,000ths to carry out a step.

45. A feasible alternative is to define the whole sequence of operations and operands by plugging on a control panel similar to those in use on some punched-card machines. This method is efficiently used on smaller computers but is laborious if large-capacity stores are involved and unpractical if long sequences of operations are carried out.

46. For larger computers there has been developed a novel technique with tremendous power. Based on the properties of the ubiquitous valve, the method enables the switches for the Gates to be set within a space of time no longer than a minor cycle; the means used to discriminate between the different possible Gate combinations are different pulse trains. Previously we have shown that numbers may be represented by pulse trains, we now change our standpoint and assert that pulse trains to set the Gates may be represented by numbers. Numbers so used will be called instructions.

47. Fig. 8 is a block diagram of a section of a Control Unit which selects one of the four basic arithmetical operations.

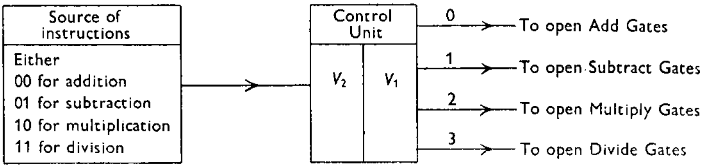


Fig. 8. Section of Control Unit.

48. After the completion of a minor cycle the Control Unit automatically seeks the next instruction which we will suppose to be a multiplication. This enters in the form of the absence of P_1 and the presence of P_2 and causes V_2 to be set in the conducting stage. The states of the two valves are held during the ensuing minor cycle and cause all P_i to be directed on line 2 to open the Gates required for multiplication.

49. Other numbers forming part of the instruction would be read by other sections of the Control Unit to cause the opening of Gates to define the other variables such as Storage Position number.

Programmes

50. For any given calculation the Control Unit must read a sequence of instructions in their correct order. Such a set of instructions is called a 'Programme'. The strength of the method is apparent when it is realized that the instructions are expressed numerically and so may be stored in the Storage Unit. They are transferred to the Control Unit at an electronic speed of the same order as that at which they are executed.

51. Methods vary in the way in which the Control Unit automatically seeks a new instruction. One of the simplest is an arrangement which causes the Control Unit, after completing the instruction in Storage Position x, automatically to read Storage Position $x+1$ for the next instruction. The rigidity of the sequence may, however, be broken by a sign-testing instruction. Such an instruction would cause the sign of the number in the Accumulator to determine whether the next instruction should be read from Storage Position $x+1$ or from another Storage Position specified in the sign-testing instruction. Sign-testing instructions give computers a high degree of automaticity. For example, a set of instructions which calculates convergent

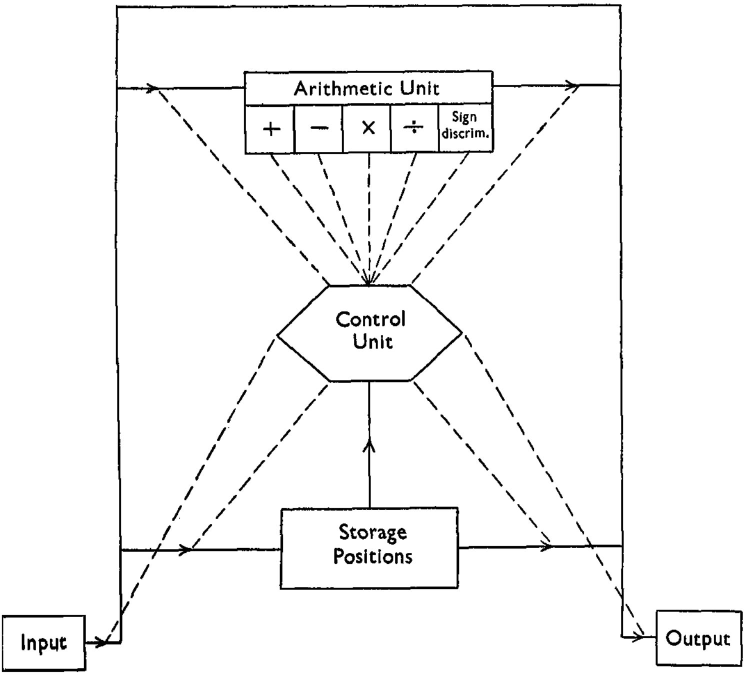


Fig. 9. Block diagram of a complete computer.

approximations may be iterated until a specified degree of accuracy has been reached, when the sign-testing instruction would direct the computer to the next set of instructions. The sign-testing instructions enable a computer to make any decision expressible as a series of such tests.

52. Since the instructions are numbers, the computer may perform any of the arithmetical operations on them. This ability permits an economy in the storage positions absorbed by instructions. For example, if it is desired to add into the Accumulator the 300 numbers in Storage Positions 200 to 499, then instead of 300 instructions each specifying a Storage Position, one 'add' instruction could be used and about three more to cause 1 to be added to the Storage Position number between each reading. This economy of storage

space is obtained at the cost of the extra operating time spent in modifying the instructions.

53. Originally the instructions are fed to the Storage Unit through the input. Once they are in, the computer functions in a fully automatic manner. It will operate on numbers which went in with the instructions, call as required for more numbers waiting at the input, and print results, all without further human intervention.

54. A block diagram summarizing the design of a computer is shown in Fig. 9. The dotted lines indicate that the transfer of information along the solid lines and the function of the Arithmetic Unit are regulated by the Control Unit causing the appropriate Gates, not now shown, to open. Though Computers may depart in detail from the design shown it is representative of principles.

The operating sequence is as follows.

55. (*a*) Insert the programme of instructions and numbers to be operated on in the Storage Positions *via* the input.

(*b*) Place in the input, in sequence, any further numbers or instructions that may be required during the course of the calculation.

(*c*) Press the start button. In successive intervals of about ·00032 seconds the computer proceeds to

(i) Read the first instruction from a Storage Position to the Control Unit,
(ii) Execute the first instruction,
(iii) Read the second instruction from the next Storage Position,
(iv) Execute the second instruction,

and so on until a sign-testing instruction directs the Control Unit to another sequence of instructions.

II. INSTRUCTIONS

56. The capabilities of computers are perhaps best understood by considering the basic set of instructions available and their use in programming a specific example.

57. Each instruction has three forms—the pulse train stored in the computer, the input-medium form, such as holes in card or tape, and the written form from which the input-medium is created. We are now concerned only with this written form in which the programme is originally constructed.

58. A typical, but in some respects simplified, set of instructions is shown in Table 1. In order to emphasize essentials and fix ideas the computer is assumed to be designed as follows.

Input. Punched cards.

Storage Unit. A Storage Position is identifiable by the symbol '*Sx*' meaning 'Storage Position *x*'. (The symbol *S*(*x*) is used for 'the contents of *Sx*'.)

Arithmetic Unit. Two sub-units to which numbers may be sent from any Storage Position. First the Accumulator (abbreviated to 'Acc') and secondly the Multiplier Register (abbreviated 'M'). The symbols '(Acc)' and '(M)' are used for the contents of Acc and M.

Output. A mechanism printing digits and letters on continuous stationery.

Control Unit. The instruction in Storage Position $x+1$ is read after carrying out the instruction in Storage Position x unless the result of a sign-testing instruction directs the Control Unit to another Storage Position.

Table 1. A typical set of instructions

Written form	Operation performed by computer
Feed next card	Values on next card read into appropriate storage positions
Add $S(x)$	Add $S(x)$ to (Acc)
(Add) $S(x)$	Clear Acc and transfer $S(x)$ to it
Subtract $S(x)$	Subtract $S(x)$ from (Acc)
(Subtract) $S(x)$	Clear Acc and transfer $-S(x)$ to it
$S(x)$ to Sy	Transfer $S(x)$ to Sy
(Acc) to Sx	Transfer (Acc) to Sx
$S(x)$ to M	Transfer $S(x)$ to M
Multiply $S(x)$	Multiply $S(x)$ by (M) and place product in Acc
Divide by $S(x)$	Divide (Acc) by $S(x)$, place quotient in M and remainder in Acc
Test $+x$	If (Acc) positive execute next the instruction in Sx. Otherwise execute next the instruction following this test instruction
Test $-x$	If (Acc) negative execute next the instruction in Sx. Otherwise execute next the instruction following this test instruction. (0 is regarded as positive by both tests)
Print $S(x)$, $S(y)$ ...	Print $S(x)$, $S(y)$ .... (The instructions necessary to print are oversimplified by the omission of both vertical and horizontal spacing instructions)

Note. Each arithmetical instruction includes a source and a destination. Only Acc is additive, consequently the effect of all transfer instructions is to replace the contents of the destination with the source contents which are not cleared. The contents of Acc are unchanged after the application of either test instruction.

59. It is suggested later that a computer could be used in a Life Office to perform some of the functions of many departments. It is not proposed to embark on a long and detailed investigation, which would require before it was commenced the postulation of the administrative and other rules of a model office, and which could be completed only by setting down the computer programme to realize those rules.

60. It is considered that a more easily defined problem will serve to illustrate principles and accordingly the printing of schedules of capital and interest included in instalments repaying a loan has been programmed.

Loan Repayment Schedules

61. A loan may be repaid either by equal total instalments of interest and principal (Type 1) or by equal payments of principal with interest on the amount outstanding (Type 2). One of three rates of interest and one of three frequencies of payment occur for each loan. The data are assumed to be punched on cards which are placed in the input in random order so far as type of loan, rate of interest, frequency of payment and term of years are concerned.

62. To illustrate the use of the sign-testing instructions and the checking capabilities, the programme is arranged to print the word 'error' and the

initial data and then pass on to the next loan if the annual instalment is not an integral multiple of the frequency. In addition it does the same for Type 2 loans if the term multiplied by the annual instalment of principal is not equal to the amount loaned. 'Error' and the amount of the error is also printed at the end of the schedule for Type 1 loans if the total principal repaid is not equal to the loan or if the total of the instalments is not equal to the annual instalment multiplied by the term. The sign-testing instruction is also used in Type 1 loans to recognize the last instalment and adopt a different method of calculating the principal and interest.

63. The formal statement of the problem follows.

Given at the input

Cards, one for each loan, in random order punched with

Amount of loan	$=L_1$
Instalment per annum	$=J$ (excluding interest in Type 2 loans)
Type of loan	$=S$ ($=1$ for equal total instalments of interest and principal or $=2$ for equal instalments of principal)
Effective rate of interest per annum	$=i=(\cdot 04, \cdot 045$ or $\cdot 05)$
Term in years	$=n$
Frequency of repayment	$=f$ (1, 2 or 4 for yearly, half-yearly or quarterly)

Required to print at the output

For each card,

1. 'Error' and initial loan details if J/f is not an integer
2. For Type 2 loans—'Error' and initial loans details if $L_1-nJ\neq 0$
3. (*a*) Instalment number $=t\ (1\leqslant t\leqslant nf)$
   (*b*) Principal outstanding before *t*th repayment $=L_t$
   (*c*) Interest included in *t*th instalment

$$=K_t=L_t\frac{i(f)}{f}\quad [i(f)=f\{(1+i)^{1/f}-1\}]$$

except Type 1 loans, $t=nf$, when $K_t=J/f-L_{nf}$

   (*d*) For Type 1 loans,
   principal included in *t*th instalment $=P_t=J/f-K_t$
   (*e*) For Type 2 loans,
   total of *t*th payment $=Q_t=J/f+K_t$

4. (*a*) $\sum_{t=1}^{nf} K_t$
   (*b*) $\sum_{t=1}^{nf} P_t$ or $\sum_{t=1}^{nf} Q_t$ for Type 1 and 2 loans respectively
5. For Type 1 loans—'Error', $L_1-\sum_{t=1}^{nf} P_t=e_1$, if $e_1\neq 0$

'Error', $nJ-\sum_{t=1}^{nf}(K_t+P_t)=e_2$ if $e_2\neq 0$

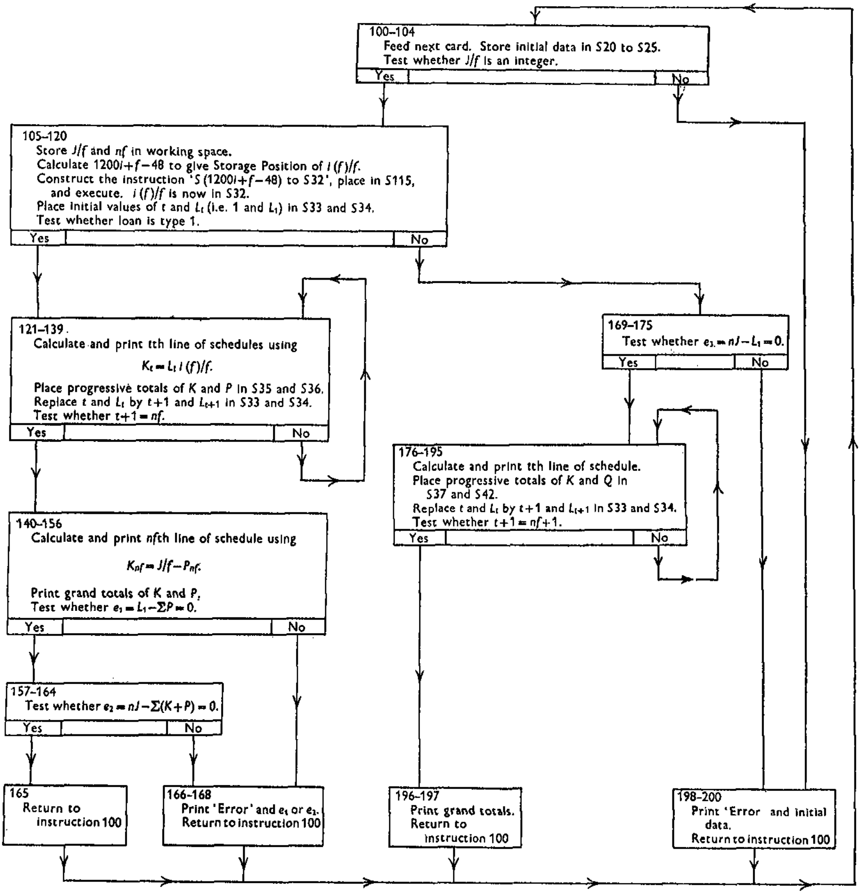
64. We assume that the basic set of instructions is that shown in Table 1 and that the currency in which the loans are recorded together with denary numbers can be dealt with directly by the computer. This latter assumption avoids the inclusion of sterling to decimal or binary conversion instructions which are not necessary for the illustration of principles; for a similar reason we assume that the digital capacity of all devices is adequate for all the loans.

65. The flow chart shows the programme in summary form and the linkage between the various sub-programmes.

66. The detailed instructions which are held in Storage Positions 100 to 200 are shown in Appendix 1.

PROGRAMME FOR CALCULATING LOAN REPAYMENT SCHEDULES—FLOW CHART

(Numbers in the top left-hand corner of the boxes refer to the Storage Positions holding the instructions)



67. Other Storage Positions are used for constants read into the computer initially with the programme, for the data read from successive cards and for working space used in the computation. The allocation of Storage Position for these purposes is shown in Appendix 2.

68. A simple example of the way in which instructions are modified is given by instructions 109 to 114. The nine possible values of $i(f)/f$ are stored in positions $1200i+f-48$ ($i=\cdot 04$, $\cdot 045$, $\cdot 05$, $f=1$, 2, 4). It is required that instruction 115 should transfer $i(f)/f$ to $S32$; this is achieved because instruction 114 transfers the numerical value of the instructions '$S(x)$ to $S32$' to $S115$ where $x=1200i+f-48$ has been computed by instructions 109 to 113.

III. SPEED

69. For most of the work of interest to an actuary, the time required to print the results will dominate the computing time. Most computers print one digit at a time serially like a typewriter; a speed of 10 characters a second can be expected. In our typical problem an average line would consist of about 30 characters allowing for spaces between columns. An 80-line schedule would be printed in about four minutes or, say, six minutes to allow for the natural caution with which all such estimates should be regarded. This is faster than the average typist could copy a completed schedule.

70. As an example of an application in which printing would not dominate, we can imagine a computer programmed to make a series of trial graduations printing the results only when a specified criterion is satisfied. Here we cannot estimate the time that would be taken because it depends on the number of trials to be made.

71. The flexibility and power of electronic methods are well illustrated by considering the different criteria of goodness of fit which could be programmed. Amongst others that come to mind are a maximum acceptable difference between total expected and actual deaths, a minimum acceptable number of changes of sign in the difference in passing from one age-group to the next, or a minimum and a maximum acceptable value of χ^2.

72. However, it is obvious that a computer is economic in man-hours only if the programme can be created in less time than is required to carry out the work by other means. This danger threatens only long, complex and non-recurring applications and is eventually overcome by the establishment of a library of standard programmes, the use of which greatly reduces programme preparation time.

73. These standard programmes in a mathematical laboratory cover frequently-arising procedures, such as the evaluation of the fundamental trigonometrical functions or of $\int_a^b f(x)\,dx$. In the latter case, the programmer would work out the steps to calculate $f(x)$ but the further steps to pass to the definite integral by a known formula would be copied automatically in the input medium from the appropriate standard programmes held on file.

74. The use of a standard programme for the trigonometrical functions illustrates the principle that when a function value is required for a computed argument it is usually more efficient computer technique to calculate from a formula than to store tabulated values and interpolate.

75. For example, in the typical programme we have stored the nine possible values of $i(f)/f$ to illustrate the principle of step-construction during a computation. In practice one would programme the direct calculation of $i(f)/f$ in order not to restrict the application to predetermined values of i and f.

IV. RELIABILITY

76. It is probably fair to suggest that the current level of reliability is such that 25% of the time available must be given up to maintenance, that accurate calculations will be made during the remaining 75% and that advances in electronic technology will steadily improve this performance.

77. A programme would be considered suitable only if it included mathematical checks and control total checks familiar to punched-card users. The typical programme illustrates the important point that the computer will itself apply these checks, a process which eliminates errors caused by a human operator omitting or not correctly applying the checking rules. In practice more checks would be included than shown in the typical programme; in the case of Type 1 loans, for example, a calculation of $a^{(f)}_{\overline{n-t}|}$ from first principles could be programmed for periodic values of t and $L_{t+1}-Ja^{(f)}_{\overline{n-t}|}$ compared with a small tolerance figure.

78. Again further automaticity can be obtained by programming one recalculation of a schedule if an error is detected, using a different mathematical basis or different allocations of the computer devices.

79. In the case of Type 1 loans the reading of the whole of the initial data into the computer can be checked by comparing L_1 and $Ja^{(f)}_{\overline{n}|}$. This is an unusual property of initial data; normally the control total checks cover the reading of the data.

80. Another checking procedure, sometimes called 'editing', is valuable in administrative applications. For example, if it is known that no new policies were issued under Table 19 after August 1939 and that all policies under the Table should mature before age 65 is attained, then the consistency of the Table 19 cards with these two rules may be programmed.

81. The above remarks may be summarized by stating that although not yet as reliable as standard punched-card machines, the high speed, automaticity and self-checking programmes give computers a potential use in the actuarial field well worthy of study.

82. The most important aspect of any computing system, be it either rules for desk-machine operators or a programme for a computer, is that the occurrence of an error, which under any system is inevitable sooner or later, should be detected as soon after it has been made as is reasonably possible.

V. A COMPUTER IN A LIFE OFFICE

Qualifications needed for responsible staff

83. Considerable study by imaginative and skilled investigators is required before it can be decided how a life office should use a computer. Before offering some speculations on this question we will consider whether, after the work has been decided upon, the staff responsible for the efficient organization of a computer should possess any special qualifications.

84. The example shows that a programme may be tedious to read but is by no means difficult to understand. Nor can it be claimed that it was difficult to produce; the only assets required are patience and an ability to express all operations in terms of the simple steps comprehensible to the computer. Further thought and experience would probably reduce the number of steps and storage positions used, both of which aims could, in certain circumstances, be not only desirable but essential.

85. There is little doubt that anyone capable of organizing efficiently a punched-card installation would be capable of organizing a computer on the same work. Only if a computer is used for work of a higher intellectual or mathematical level will a corresponding increase in the qualifications of the supervisory staff be required.

86. Above the supervisory level, however, the increased scope of the potentially mechanizable work gives the whole subject of office machinery greater importance than hitherto. Before the advent of computers, this had led to government and commercial action in establishing Organization and Methods departments, whose duties include the study and application of new office aids.

87. The view is put forward that in future the management of any large organization will be able to preserve its competitive position only if it makes full use of electronic aids. This implies a raising of the managerial level at which initiative is taken and informed decisions made in the mechanization field.

Capability of a computer in a life office

88. We will now speculate on the capabilities of a computer in a life office. First we can assert that a computer could undertake all the work presently mechanized on punched-card machines; in the larger offices this would be accomplished with less operating staff and probably more quickly. Some saving would be made in the punching and verifying staff but, since the amount of information to be punched would probably not be greatly reduced, it follows that the saving in punching staff would not be large.

89. The existing mechanized work includes the preparation of renewal notices, valuation data, commission statements, bonus notices and the printing of policies. A second and obvious assertion is that an electronic computer would be capable of mechanizing a wider area of this work and so reducing its purely clerical and desk-calculating-machine content. This advantage accrues from the almost unlimited number of arithmetical operations, including division, which the computer can be programmed automatically to perform. For example, a valuation by Lidstone's Z method could be calculated without human intervention after the data had been given to the computer.

90. To contemplate the use of computers to achieve existing results with some increase in scope, but without any change in fundamental office organization, is a natural first approach. Indeed an office would be wise to pass from contemplation to paper planning, if not practical trial, of this limited objective in order to learn the new techniques before exploring the more revolutionary possibilities.

91. Much exploration has taken place in North America. The keynote of the special presentation and discussion by the Society of Actuaries Committee

on New Recording Means and Computing Devices was expressed in four points (3).

1. A great deal of progress has been made in the development of electronic machinery which can now be regarded as sufficiently reliable and versatile for effective use in the day-to-day office work of an insurance company.

2. The importance of available electronic computers as complete procedure appliers is so great that it outweighs by far the limitations imposed by the fact that they do not now do some things, such as sorting, printing and automatic file maintenance, as well as might be desired.

3. To use electronic computers effectively in insurance work, some far-reaching changes in current day methods and organizations appear necessary. Furthermore, moderate sized companies as well as large ones should be able to arrange their work in such a way as to be able to take advantage of these new tools.

4. The development of effective insurance systems will demand a fundamental understanding of the basic requirements underlying existing procedures in many departments of the company as well as a good understanding of how mathematical machines can be used to satisfy those requirements. Insurance knowledge and know-how are by far the most important ingredients, and actuaries should be able to contribute a great deal.

92. The Committee described one of many possible solutions relying for its practical value on the assumption that a company can and should recast its operations so as to consolidate functions which are now scattered over different departments. This consolidation would create the volume of work necessary to keep the computer gainfully employed and avoid much duplication that otherwise would exist.

Consolidated Functions Approach

93. Briefly, this suggested Consolidated Functions Approach permits all results to be obtained from two files of punched cards: (1) a notice-writing file held in policy-number order and (2) a calculation file held in month-of-issue order within valuation groups. The novelty of the proposal lies in the use of only two files of cards and the production from them at each policy anniversary of the following information quoted from Davis (2).

a. The annual dividend payable on each policy.
b. The loan interest due on each policy so encumbered.
c. The policy cash value on each policy outstanding.
d. The amount of additional insurance purchased by the annual dividend; also the previous and current totals of such additional insurance.
e. The current amount of dividends with interest for each policy.
f. The cash value of the dividend additional insurance at two successive anniversaries.
g. Determination that a particular policy is due to mature, become fully paid, or expire (including expiries of extra benefits and partial expiries of insurance premiums).
h. Classified totals of the policies by valuation groups for reserve calculation purposes (i.e., totals of policies, insurance, two kinds of disability insurance, three kinds of D.I. insurance, etc.).

The information would be produced in punched-card form and posted in printed form to a policy-history card.

94. The above computer processes not only cover the functions of many separate departments but they give a new approach to two organizational questions. In the first place, cessation options such as surrender and free policy values are calculated for every policy on its anniversary so as to be

immediately available when an inquiry is made, with consequent relief to both the office and policyholder. Secondly, a revaluation on policy anniversary has a similar effect of removing a peak of work.

95. One general conclusion reached by the Committee is that a worthwhile increase in computer efficiency is obtained if the data are presented to it in some order. This suggests that, at least for some time, computers will be supported by some auxiliary sorting machine.

96. The Committee's latest report (4), which has recently been received in this country, confirms their earlier findings and includes a detailed description of the Consolidated Functions Approach. The Report implies that the practical trial of an isolated operation, suggested in § 90, should be made before embarking on a major investigation.

97. The Consolidated Functions Approach gives an indication in general terms of what may ultimately be achieved. It illustrates that the maximum gain may perhaps be obtainable only if we are prepared to discard traditional procedures and forms of organization. A particular office will be able to produce the detailed plans necessary before a major decision can be taken only after a long investigation, on unfamiliar lines, of the work in nearly all departments in the office and of the office's external obligations to make statutory returns, to satisfy its auditors and sometimes to satisfy the Courts.

Other computations

98. Other work for a computer, were one available in an office, would include actuarial calculations such as graduations and premium recalculations. Further use would embrace work not now done because it is impracticable by any other means. Examples are valuations on several bases, mortality investigations with many classifications and the construction of tables of commutation columns, premiums or other functions for complete ranges of arguments, such as is not now the case for joint lives. It must be stressed that it is not work of this mathematical character which will justify a computer in an office. The potential strength of a computer lies in its ability to process a large mass of repetitive and simple day-to-day work.

99. Work of importance in the mathematical field has already been carried out for the Institute of Actuaries and the Faculty of Actuaries by J. Lyons and Co. Ltd., whose staff—after consultation with the Joint Mortality Committee—produced the programme for computing the two-life annuity values for the new $a(55)$ tables on LEO. Fed into the computer were values of:

p_x and $p_{[x]}$ for both sexes at all ages, v for seven rates of interest.

100. From these data the computer automatically printed values of:

a_{xy} using the formula $vp_xp_y(1+a_{x+1:y+1})$
$a_{\overline{xy}}$ using the formula $a_x+a_y-a_{xy}$
$a_{[\overline{xy}]}$ using the formula $\phi_x a_x+\phi_y a_y-\phi_x\phi_y a_{xy}$ (where $\phi_x=p_{[x]}/p_x$)

101. That the most efficient computer method may differ radically from existing practice is illustrated here because values of a_x and a_y were not fed into the computer but calculated by it as required.

102. The use of an electronic computer for the $a(55)$ tables is believed to be the first in the production of official tables by a professional actuarial body.

103. Again, there are possibilities beyond mere elaborations of existing methods. The ability to perform a greater amount of arithmetic should permit one to develop new methods, taking into account many more factors, in such work as population projection and economic forecasting.

Price

104. For the sake of completeness some mention must be made of price, but any statement would be guesswork at this early stage in the development of the computer industry in this country. In North America, where the commercial marketing of computers is further advanced, prices range from $60,000 to $1,000,000. The upper limit is not easily fixed; a machine with special input devices supplied to the U.S. Government has been reported in the Press to have cost $3,100,000. The higher priced computers offer greater automaticity and speeds because they contain more storage facilities and possibly multiple inputs and outputs.

105. Whether a computer is an economic proposition can be decided only after the detailed investigation mentioned has been completed and estimates made of the value of the staff saving, increased services to policyholders and quicker internal figures.

VI. SUMMARY

106. It has been shown that the features which distinguish electronic computers from their ancestors—abaci and punched-card machines—are:

(*a*) *Automaticity*. A long programme of arithmetical and recording operations may be performed without human intervention.

(*b*) *Discrimination*. A programme may, and usually does, cause the computer to vary the sequence of execution of the steps according to the value of numbers read in, or according to results previously calculated. This is achieved by testing whether a number is positive or negative, with a different subsequent step in each case. (This ability to select one of two alternatives is the cause of the too frequent and erroneous use of the verb 'think' in descriptions of the functions of these computers.)

(*c*) *Storage*. A large quantity of numerical data arising externally *via* the input, or generated in executing the programme, may be retained and re-used.

(*d*) *Speed*. The time to perform an operation is measured in thousandths of a second. For example, the Manchester machine will make 320 additions or subtractions in one second. (Increased speed was the original motive which caused electronic devices to be assembled as computers. Today, in the author's opinion, the subsequently developed automaticity, discrimination and storage are the more important features.)

107. Although some of the opinions expressed are based on assumptions which would be better called guesses, the paper has not described technical visions. The hardware mentioned can be seen working at the speeds quoted and with the reliability stated. Properly exploited electronic computers would permit Phillips's prediction quoted in § 1 to be fulfilled. To realize their full value, an office must make a detailed study on possibly unfamiliar lines of the work of all departments and be prepared eventually to change the traditional form of organization.

APPENDIX 1

Programme for calculating loan repayment schedules

Storage position	Instruction	Contents of Accumulator after instruction executed
100	Feed next card	
101	(Add) *S*(21)	J
102	Divide by *S*(25)	Remainder $J/f=R$
103	Subtract *S*(9)	$R-1$
104	Test + 198	$R-1$ (*a*)
105	(M) to *S*30	$R-1$ (*b*)
106	*S*(25) to *M*	$R-1$
107	Multiply *S*24	nf
108	(Acc) to *S*31	nf
109	*S*(5) to M	nf
110	Multiply *S*(23)	$1200i$ (*c*)
111	Add *S*(25)	$1200i+f$
112	Subtract *S*(6)	$1200i+f-48=x$
113	Add *S*(3)	'$S(x)$ to $S32$'
114	(Acc) to *S*115	'$S(x)$ to $S32$'
115	*S*(*x*) to *S*32	'$S(x)$ to $S32$'
116	*S*(9) to *S*33	'$S(x)$ to $S32$'
117	*S*(20) to *S*34	'$S(x)$ to $S32$'
118	(Add) *S*(22)	S
119	Subtract *S*(11)	$S-2$
120	Test + 169	$S-2$
121	*S*(32) to M	-1
122	Multiply *S*(34)	$L_t(i)_f/f$ (*d*)
123	(Acc) to *S*35	$L_t(i)_f/f=K_t$
124	Add *S*(37)	$\sum_{x=1}^{t} K_x$
125	(Acc) to *S*37	$\sum_{x=1}^{t} K_x$
126	(Add) *S*(30)	J/f
127	Subtract *S*(35)	$J/f-K_t=P_t$
128	(Acc) to *S*36	$J/f-K_t=P_t$
129	Add *S*(38)	$\sum_{x=1}^{t} P_x$
130	(Acc) to *S*38	$\sum_{x=1}^{t} P_x$
131	Print *S*(33), *S*(34), *S*(35), *S*(36)	$\sum_{x=1}^{t} P_x$
132	(Add) *S*(34)	L_t
133	Subtract *S*(36)	$L_t-P_t=L_{t+1}$
134	(Acc) to *S*34	$L_t-P_t=L_{t+1}$
135	(Add) *S*(33)	t
136	Add *S*(9)	$t+1$
137	(Acc) to *S*33	$t+1$
138	Subtract *S*(31)	$t+1-nf$
139	Test − 121	$t+1-nf$ (*e*)
140	*S*(34) to *S*36	$t+1-nf$
141	(Add) *S*(30)	J/f
142	Subtract *S*(36)	$J/f-P_{nf}=K_{nf}$
143	(Acc) to *S*35	K_{nf}
144	Add *S*(37)	$\sum_{x=1}^{nf} K_x$
145	(Acc) to *S*37	$\sum_{x=1}^{nf} K_x$
146	(Add) *S*(36)	P_{nf}
147	Add *S*(38)	$\sum_{x=1}^{nf} P_x$
148	(Acc) to *S*38	$\sum_{x=1}^{nf} P_x$
149	Print *S*(33), *S*(34), *S*(35), *S*(36)	$\sum_{x=1}^{nf} P_x$
150	Print *S*(37), *S*(38)	$\sum_{x=1}^{nf} P_x$
151	(Add) *S*(20)	L_1
152	Subtract *S*(38)	$L_1-\sum_{x=1}^{nf} P_x=e_1$
153	(Acc) to *S*39	$L_1-\sum_{x=1}^{nf} P_x=e_1$
154	Test − 166	$L_1-\sum_{x=1}^{nf} P_x=e_1$ (*f*)
155	(Subtract) *S*(39)	$-e_1$
156	Test − 166	$-e_1$ (*g*)
157	*S*(24) to M	$-e_1$ (*h*)
158	Multiply *S*(21)	nJ
159	Subtract *S*(37)	$nJ-\sum_{x=1}^{nf} K_x$
160	Subtract *S*(38)	$nJ-\sum_{x=1}^{nf}(K_x+P_x)=e_2$
161	(Acc) to *S*40	$nJ-\sum_{x=1}^{nf}(K_x+P_x)=e_2$
162	Test − 166	$nJ-\sum_{x=1}^{nf}(K_x+P_x)=e_2$
163	(Subtract) *S*(40)	$-e_2$
164	Test − 166	$-e_2$
165	Test + 100	$-e_2$ (*i*)
166	Print *S*(12), *S*(39), *S*(40)	$-e_2$
167	(Add) *S*(9)	1 (*j*)
168	Test + 100	1
169	*S*(31) to M	0
170	Multiply *S*(30)	nJ
171	Subtract *S*(34)	$nJ-L_1=e_3$
172	(Acc) to *S*40	$nJ-L_1=e_3$
173	Test − 198	$nJ-L_1=e_3$ (*k*)
174	(Subtract) *S*40	$-e_3$
175	Test − 198	$-e_3$ (*k*)
176	*S*(32) to M	$-e_3$
177	Multiply *S*(34)	$L_t i(f)/f=K_t$
178	(Acc) to *S*35	$L_t i(f)/f=K_t$
179	Add *S*(37)	$\sum_{x=1}^{t} K_x$

APPENDIX 1 (*continued*)

Storage position	Instruction	Contents of Accumulator after instruction executed	Storage position	Instruction	Contents of Accumulator after instruction executed
180	(Acc) to $S37$	$\sum_{x=1}^{t} K_x$	190	(Add) $S(33)$	t
181	(Add) $S(30)$	J/f	191	Add $S(9)$	$t+1$
182	Add $S(35)$	$J/f+K_t=Q_t$	192	(Acc) to $S33$	$t+1$
183	(Acc) to $S41$	$J/f+K_t=Q_t$	193	Subtract $S(31)$	$t+1-nf$
184	Add $S(42)$	$\sum_{x=1}^{t} Q_x$	194	Subtract $S(9)$	$t+1-nf-1$
			195	Test $-$ 176	$t+1-nf-1$ (*l*)
			196	Print $S(37)$, $S(42)$	$t+1-nf-1$
185	(Acc) to $S42$	$\sum_{x=1}^{t} Q_x$	197	Test $+$ 100	$t+1-nf-1$ (*m*)
186	Print $S(33)$, $S(35)$, $S(41)$	$\sum_{x=1}^{t} Q_x$	198	Print $S(12)$ and $S(20)$ to $S(25)$	(*n*)
187	(Add) $S(34)$	L_t	199	(Add) $S(9)$	1
188	Subtract $S(30)$	$L_t-J/f=L_{t+1}$	200	Test $+$ 100	1
189	(Acc) to $S34$	$L_t-J/f=L_{t+1}$			

Notes

(*a*) We assume for convenience that if $R \neq 0$ it will be a positive integer. An unrestricted test that (Acc) $= 0$ is illustrated by instructions 151–156.

(*b*) Instruction 102 placed J/f in M, instruction 105 therefore transfers it to $S30$.

(*c*) See Appendix 2, footnote (*a*).

(*d*) In this and other multiplications is omitted an add instruction to round off the product to a specified degree of accuracy.

(*e*) $t+1-nf$ becomes positive when $t+1=nf$; L_{nf} is then in $S34$ and is transferred to $S36$ as the value of P_{nf}.

(*f*) If $e_1 < 0$ the programme jumps to the error-printing instruction 166.

(*g*) If $e_1 > 0$ the programme jumps to the error-printing instruction 166.

(*h*) Only if $e_1 = 0$ are instructions 157–164 executed to test $e_2 = 0$.

(*i*) Since this test is applied only if $e_2 = 0$ the contents of the Accumulator will be positive and a new loan will be started by the return to instruction 100.

(*j*) To ensure positive contents of the Accumulator so that the next instruction will return the computer to instruction 100.

(*k*) If $e_3 \neq 0$ the error-printing instructions of the initial detail are executed.

(*l*) Another line of the schedule must be printed if $t+1 < nf$.

(*m*) Only if (Acc) $= 0$ will this instruction be executed hence its effect is always to return to instruction 100.

(*n*) Here the contents of the Accumulator depend on whether the preceding instruction was number 104, 173 or 175.

APPENDIX 2

Programme for calculating loan repayment schedules

Allocation other than to instructions of Storage Positions

Constants	Read from cards	Read from various computer sources during computations (Working Space)		
·04 in $S1$	L_1 to $S20$	J/f	to	$S30$
$\frac{1}{2}[\cdot 04(2)]$ in $S2$	J to $S21$	nf	to	$S31$
'$S(000)$ to $S32$' in $S3$ (*a*)	S to $S22$	$i(f)/f$	to	$S32$
$\frac{1}{4}[\cdot 04(4)]$ in $S4$	i to $S23$	t	to	$S33$
1200 in $S5$	n to $S24$	L_t	to	$S34$
48 in $S6$	f to $S25$	K_t	to	$S35$
·045 in $S7$	0 to $S37$	P_t	to	$S36$
$\frac{1}{2}[\cdot 045(2)]$ in $S8$	0 to $S38$	$\sum_{x=1}^{t} K_x$	to	$S37$
1 in $S9$	0 to $S42$	$\sum_{x=1}^{t} P_x$	to	$S38$
$\frac{1}{4}[\cdot 045(4)]$ in $S10$		$L_1 - \sum_{x=1}^{nf} P_x$	to	$S39$
2 in $S11$		$nJ - \sum_{x=1}^{nf} (K_x + P_x)$		
'ERROR' in $S12$ (*b*)		or $nJ - L_1$	to	$S40$
·05 in $S13$		Q_t	to	$S41$
$\frac{1}{2}[\cdot 05(2)]$ in $S14$		$\sum_{x=1}^{t} Q_x$	to	$S42$
$\frac{1}{4}[\cdot 05(4)]$ in $S16$				

Notes

(*a*) The constant in $S3$ is used to construct an instruction which sends the value of $i(f)/f$ to $S115$. The nine possible values of $i(f)/f$ have been placed in Storage Positions $1200i+f-48$. During the execution of the programme $1200i+f-48$ is added to the numerical code equivalent of '$S(000)$ to $S32$' to give '$S(1200i+f-48)$ to $S32$'.

(*b*) $S12$ contains the numerical code equivalent of the letters ERROR. Consequently the instruction 'Print $S(12)$' causes the word 'ERROR' to be printed.

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10. *Mathematical Tables and Other Aids to Computation.* Each issue contains a section devoted to developments in Automatic Computing.

ABSTRACT OF THE DISCUSSION

The President (Mr W. F. Gardner), on behalf of the members present, offered a welcome to the guests. He said that it was fitting that he should record that, on the subject of electronic computers, American colleagues in the Society of Actuaries had been well in advance of those in the United Kingdom both in time and in depth of investigation. In 1948, the Society of Actuaries appointed a special committee to consider New Recording Means and Computing Devices. In 1951 that committee produced a printed report for the benefit of the members of the Society, and in the Spring of 1952 a morning session was devoted to considering the findings of the committee up to that date. Then, in September 1952, a special meeting of the Society was held, to which were invited nominees of other interested bodies. Actuaries all over the world were, or would be, conscious of the debt that they owed to the Society of Actuaries for their most valuable survey of that important subject.

As far back as 1936 a paper was submitted to the Institute by Mr William Phillips advocating the use of the binary scale as a basis for computing machines. He understood that all British and many American computing machines currently employed the binary scale. It was therefore appropriate that Mr Phillips, who had kept in close touch with the whole subject, should close the discussion. Mr Phillips not only advocated the binary scale, but he produced at the meeting in 1936 a sample of a mechanical binary calculating apparatus designed by himself. Mr Michaelson, the author, was not able to bring to the Hall an electronic computer, but he had done the next best thing in arranging to show a film of one.

Mr R. L. Michaelson, in introducing the film, said that it had been made by the staff of the University Mathematical Laboratory in Cambridge, and he desired to express thanks to Dr Wilkes, Director of the Laboratory, for allowing it to be shown.

The film gave an impression of what went on when it was desired to solve a problem on EDSAC. EDSAC was the large-scale Electronic Digital Computer built by the University laboratory. Its input was 5-hole teleprinter tape, instructions and numbers being punched in the tape, and a library sub-routine previously punched on pink tape would be seen being automatically reproduced. The tape-reader passed the instructions which had been punched into the tape into EDSAC's storage, which took the form of mercury delay lines. The binary numbers representing the code form of the instructions would be exhibited on cathode-ray tubes. He mentioned that EDSAC had no cathode-ray tube storage; the tubes seen belonged to oscilloscopes—instruments giving a visible indication of the contents of the mercury stores.

The instructions having gone in, the tape then contained constants, and it would be seen that instead of being read continuously, it would stop and start because calculation was taking place. Some of the calculation would be shown on the cathode-ray tubes, a dot representing one and the absence of a dot representing nought. It would be seen that those numbers changed, but so quickly that it would be impossible to tell the value of the numbers.

Finally, EDSAC's output, a teleprinter, was seen typing the answer, which turned out to be correct. However, as proof that no machine was infallible, previous sight was given of the result of another problem and in that case EDSAC had produced obvious nonsense.

At the conclusion of the film, Mr Michaelson, continuing, passed to the introduction of his paper, saying that it had been suggested to him that the paper gave an impression that electronic computers must compute in binary arithmetic. That of course was not so. ENIAC, the grandfather of the modern monsters, was a denary machine. Nevertheless, most of the computers were binary. Whether there would be a trend away from binary was speculative but possible.

Also, he desired to offer a definition of a computing machine, which was primarily to distinguish it from desk calculators and the more complicated punched-card machines. A computer could modify its instructions; thus the instruction 'Add the contents of Storage Location No. 1' could be modified to 'Add the contents of Storage Location No. 2' and so on. That allowed a computer to execute more instructions than it could hold at any one moment of time. The definition was, therefore, 'A computer is a calculating machine capable of performing without further human intervention more operations than can be set in it at any one time'. However versatile modern punched-card machines were believed to be, they could not, without resetting, do more than could be physically and visibly set up on them at the start.

Mr B. T. Ramm, in opening the discussion, said that it was not an easy task to explain to a non-technical audience the workings of such a complex piece of equipment as an electronic computer, but by concentrating on essential principles and by providing an abundance of visual aids the author had carried it out successfully. Anyone who had read the paper and had had the patience to unravel the strands of the specimen programme could not fail to have obtained quite a deep understanding both of the construction of the machine and the way in which it could be used. Mathematicians had always been anxious to avoid the labour of computation, and since actuaries could not, like the pure mathematician, escape it by expressing their results as a formula, or even merely prove the problem capable of solution, they had always shown considerable interest in computing machines, as was illustrated by the number of papers on such machines which had been read before the Institute. The number of those papers was in marked contrast to the few references to the sorting and tabulation of data by mechanical means, a problem that in actuarial work could not be separated from that of computation at any time and particularly when considering the application of the type of machine described in the paper.

Mathematicians were accustomed to thinking in abstract terms, and their inventive genius had tended to run ahead of the technical resources at their disposal. It was therefore perhaps not so surprising as it might seem at first sight that all the basic principles of the electronic computer were included in the analytical engine designed by Babbage over a hundred years previously, and that Phillips described in his paper in 1936 a machine that could almost be used as a mechanical illustration of the arithmetical circuits of the electronic computer. The author was, however, much more fortunate than Phillips, in that he did not have to combine a description of the machine with advocacy of an unusual system of notation, since the electronic machine automatically converted numbers from the denary to the binary scale and back again. Even so, since that operation was the next slowest the machine had to perform after that of reading the input data and printing the output, quite a good case could still be made for the octonal scale.

The author could well have given an indication of the great range of size and speed among the different types of electronic computer in existence, and discussed rather more specifically how that affected their application to life-office work. The storage capacity of the smallest machines was measured in hundreds of digits, but that of the largest in hundreds of thousands. There was a similar variation in the speed at which arithmetical operations were carried out, the time taken for an addition being measured in microseconds in the fastest machines, and milliseconds in the slower. Below those again were the machines, which the author excluded from his paper by definition, that performed a limited number of simple set arithmetical operations. Although those machines had been excluded from the paper, they could not be excluded from a consideration of the applications of the more versatile computer, since it was they rather than current methods which must be considered as an alternative.

The machines so far constructed in America had tended to be concentrated at either the lower or the upper end of the size range, and it would seem to be clear that quite a different technique must be adopted when considering the application of a large, fast machine to the work of an insurance office, from that required by the smaller, slower type. Important questions were therefore involved as to the lines which future development work should take. Most of the report of the Committee of the American Society of Actuaries dealt with the use of a fairly small, slow type of machine, whereas the paper would appear to be concerned primarily with the larger type of computer. It was probably that difference that had caused the contrast between the report of the American Committee, who recommended that the valuation work should be spread evenly over the whole year, and the rather more grandiose vision of a valuation carried out on several different bases before lunch.

The larger type of machine was designed primarily to carry out complex scientific and engineering calculations, where the computing work was very large in relation to the input and output data. Such problems did occur in the statistical and actuarial fields, examples being the solution of the large sets of linear equations beloved by econometricians, and the graduation of a mortality table. For that sort of work the large computer was ideal, and so powerful that there was a strong temptation to obtain numerical solutions to calculations of no possible practical value. Graduations and the preparation of tables were not, however, part of an actuary's every-day routine, and when those calculations arose they were most appropriately done by some central computing service operating such a machine. They certainly would not justify its purchase by a life office. Even valuation work alone would hardly justify its use, and it was likely that that could be carried out far more economically using punched cards in conjunction with a calculating punch whose operation was based on the same arithmetical circuits as the computer, but did not possess its ability to be programmed to carry out a chain of different calculations and its power of discriminating between the different results of those calculations and adjusting its conduct accordingly. It seemed to him that it was those powers, together with that of storing information internally until it was required, rather than its ability to perform arithmetic almost instantaneously, that gave the machine its future in an office. They enabled several different calculations to be performed from one passage of data through the machine and that was the essence of the American Consolidated Functions Approach, and must be essential to the economic use of the machine. They also gave the machine its great flexibility, so that it could deal with any new situation which might arise, provided—

and it was a very important proviso—that it had been foreseen by the 'programmer'.

Although that meant that the machine did not have to be 'tailor-made' to suit the requirements of each individual office, it was still essential for its economic operation that the ratio of its computing speed to its input and output speed was appropriate to the work it was to do. It was obviously inefficient for the computing circuits to be standing idle for long periods while data were being fed into the machine or the answer was being printed. The machines existing that had sufficient storage capacity to obviate the need for much mechanical sorting and handling of punched cards had not as yet high enough input and output speed to make full use of their powers of calculation, and considerable research was needed before the ideal machine could be designed—research not only into engineering problems but, as the author had pointed out, into the work done by a life office and how it could best be organized to be carried out by a computer. Not only must the ratio of computing to input and output speeds be correct, but the speed of the machine throughout must be such that it was kept fully occupied, since, although it might be cheaper to employ a machine than to carry out the work by manual methods, even when the machine was being used well below capacity, it would soon become uncompetitive when that type of computer came into general use.

There were, therefore, two alternative approaches to the problem. Either a comparatively slow and cheap machine could be used, working from punched cards and requiring a reorganization of current methods rather than a revolution, or an attempt could be made to develop a fast enough input and output system to enable full advantage to be taken of the capabilities of a large-scale computer. Current work on the speeding-up of the rate at which data could be fed into or taken from the machine would appear to be following along two different lines, increased speed being obtained either by the feeding in and printing out of large blocks of information at the same time, or by the use of high-speed magnetic tape or photographic film. Magnetic tape contained the data in the form of magnetized spots on its surface and could feed information into the machine at perhaps some fifty times the speed of punched cards or the normal type of perforated teleprinter tape. Since the output tape could carry all the spacing and case shift instructions needed to print the final answer correctly, it gave a much more flexible type of output than could be obtained by printing large blocks of numbers at the same time. The data could be recorded on the tape either from a keyboard or automatically from punched cards, and since a number of operators could be preparing reels or boxes of tape at the same time, just as several automatic typewriters might simultaneously print information from a number of reels of tape, full advantage could be taken of the high speeds at which the tape could be fed into or taken from the machine. That system also suggested the possibility that the tape, instead of being processed by the office's own computer, might be sent for processing to a central computing service. The output of the computer would then be returned in tape form, which the office would pass through its own automatic typewriters or re-convert into punched cards.

Those considerations, together with the large amount of research and development work still to be done, suggested that the adaptation of the larger type of computer to life-office work required a cooperative effort rather than that individual offices should each attempt to solve the same problems independently and end up by competing with each other in trying to sell time on their spare computer-capacity.

The use of the smaller type of computer, however, did not present the same problems and would require little more than a reorganization and consolidation of existing punched-card files. Moreover, it would appear to be an essential first step in the consideration of the employment of the largest type of machine. Unfortunately, it was only the larger computer which was then on the market in the United Kingdom, the sole available alternative being the much simpler calculating punch.

Mr E. J. W. Dyson agreed with the author that it was desirable for the profession to make its requirements known while there was still time to influence design.

On reading the paper he was struck particularly by two phrases. One, in § 72, read:

> However, it is obvious that a computer is economic in man-hours only if the programme can be created in less time than is required to carry out the work by other means.

The other was in § 98:

> The potential strength of a computer lies in its ability to process a large mass of repetitive and simple day-to-day work.

The input and output mechanisms were clearly of prime importance when considering the desirable characteristics of a computer for commercial use. Most existing computers had a limited storage capacity—amply sufficient for the type of work for which they were originally intended, but quite insufficient if the computer were to be used to store basic information which would be needed in commercial work. For example, the figure of 600,000 binary digits, referred to by the author as the storage capacity of the magnetic drum of the Manchester machine, would be insufficient to store even a list of policy numbers in force in a medium-sized life office. The basic data had, therefore, to be stored outside the machine, and it was necessary to have a means whereby information could be quickly transferred into the machine. To enable full use to be made of a computer the time taken to print the result should be comparable with that used in the calculation, which was not always so with existing machines. He suggested that the problems of high-speed input and output—particularly the latter—would have to be solved, as no doubt they were well on their way to being, if computers were to have the maximum commercial use.

On the other hand, compared with certain other applications of computers, the amount of work which had to be carried out on the basic data was rather limited. For reasons of cost it was unlikely that a company would consider the installation of a machine with a computing capacity greatly in excess of that needed for its day-to-day operations. That would not make it impossible to perform the operations, such as valuations on several bases and mortality investigations with many classifications, referred to by the author, but it might increase the complexity of the programming involved. Although the results of those various calculations would be useful, it was necessary for most people to get along as best they could without them, because their value was outweighed by the cost. If a computer were available the economic criterion was not altered. The range of operations which could feasibly be performed was extended; that was all.

In the practical application of a computer to office work, as was mentioned several times in the paper, the most efficient computer technique might differ radically from the best existing practice.

To touch for a moment on programming, he desired to say how much he appreciated section 11 and appendix 1 of the paper. A type of examination question frequently set contained a sentence something like: 'Draft a suitable set of instructions for a non-actuarial staff who will carry out the work.' He was always surprised that so few candidates went into sufficient detail, yet instructions which would be sufficiently detailed for a human staff would be far too complex for a computer. It was so easy to forget that the computer could only perform a very limited range of operations, and that its work had to be broken down into steps comprised of things in that range. The attributes of patience and an ability to express all operations in terms of the simple steps comprehensible to the computer—mentioned in § 84—were perhaps rarer than the author thought.

There were always two things to be considered—the information which was wanted and the way by which it was to be obtained. The information wanted was in principle the same whether a computer was available or not, but the methods of marshalling the information needed to be thought out afresh. Such consideration had obviously to take place at the highest level in each office, since it might well result in a complete recasting of existing methods and a re-allocation of responsibilities among the staff. To provide a background of knowledge for a preliminary approach—and it was none too early for such an approach to be made—the paper would be of great value. The author would, he felt sure, agree that such a background, though necessary, could be no substitute for the detailed study which had to be made before the introduction of a computer could be justified in any particular office. It was to be hoped that when such a detailed study had been made a description of the methods used at least, even if not the results arrived at, might be published as a help to those thinking of following suit.

Mr D. J. Leapman supported the previous speaker's view that the paper had certainly not come too early. The report of the sub-committee of the North American Society of Actuaries had been in the hands of many members in the United Kingdom for some months, but it was in some respects rather theoretical. He had been privileged to see a programme—prepared, he need hardly say, by a North American actuary—which contained seven sub-routines for the complete processing of a policy. It was suggested that there would be several alternatives from among which each sub-routine would be chosen; the choice would depend on the details of the policy being dealt with. The amount of programming involved was quite appreciable and, if the use of those machines was coming in the United Kingdom, it would not do to shelve the idea for two or three years and hope that two years later a complete system would be working. Considerable thought was needed to put one of those machines into action, and much more preparatory work than was needed for punched cards.

There were one or two small technical points in the paper to which he desired to refer. In § 3 the author referred to ACE as being officially regarded as a small-scale model. ACE was designed as a small-scale model in the days when it was believed that a large high-speed storage was an essential part of the general-purpose computer. At the time of speaking the emphasis had rather been laid on large moderate-speed storage with a smaller high-speed store, and he thought that the owners of ACE would be satisfied with the same machine if it had a drum, and would regard it not as a small-scale model but as a full-scale computer.

In § 32 there was a reference to the Manchester machine, of which he had some personal experience. He gained the impression from that paragraph that the Manchester machine transferred numbers from the slow store to the high-speed store just before use; that would, of course, be ridiculous, since no gain in speed would result. What happened was that large blocks of numbers were transferred from the drum to the high-speed store in one operation, either one-eighth or one-quarter of the fast storage being refilled from the slow-speed store; when all the data in the high-speed store had been used, another block was transferred from the drum.

In § 57 there was a reference to three forms of representation. He felt sure that the author would agree that in machines using cathode-ray tubes or a magnetic drum there were four such forms; the static form had to be translated from a store position to an arithmetical unit by changing it into dynamic form first, passing it through the circuits, and making it static again on the drum.

In § 69 reference was made to the time necessary for the preparation of a loan schedule. There was a current tendency to use higher-speed printers, and tabulator-type printers were being attached to machines. They would print two complete lines in about a second. In other words, they printed at the normal tabulator speeds, and the schedule could then be printed in about 40 seconds. Excluding binary to decimal conversion, there were only 19 instructions to be obeyed by the machine in each of the lines of the loan schedule; that represented a very small time element which would not noticeably increase the printing time.

There had been an earlier reference to the use of binary arithmetic in the machines. Recent improvements in decimal counters might, however, start a move towards decimal machines again. On the other hand, for sterling and other non-metric quantities there were few advantages to be gained from a decimal machine save in getting the information into the machine, and assuming that represented only a small part of the calculating time—as it should if any of the machines then existing were to be used efficiently—not much would be gained by using decimal machines.

In § 85 the author referred to the ease of organizing a computer compared with a punched-card installation on the same work. It was not, however, easy to visualize how the computer could be used on the same work. It might seem a small point, but in the use of punched cards a human agent was required. If punched cards were put through a sorter, the human agent afterwards picked them out, and could tell by visual means when they were all sorted; it was not necessary to count the passage of each card. It was sometimes possible to programme a computer to find out whether there were more data to process, but frequently it was necessary to count. The computer had to be programmed for the control side of the operation, and that was more difficult than programming the punched-card machine. So far as programming was concerned, in his view a rather higher intellectual standard was needed for work on a computer than was required for organizing a punched-card installation.

There were instances when computers would save a considerable amount of punching, more than was suggested in § 88, and it might be of interest if he were to give a brief example. Assuming that a computer with punched-card facilities was being used for a group pension scheme, of the most common type, with standard retirement ages, etc., all that would be required was a general programme which would contain, among other things, the tables of RNI and NR rates.* For each scheme it would be necessary to feed in the amount which

* For definitions of these symbols see *J.I.A.* LXXVII, 379.—Eds.

members contributed per future service unit, a table of benefits, the commencing date, the reference number of the scheme, the maximum and minimum entry ages and a code specifying whether the salary was expressed per week, per month or per year. On each employee's card it would then be necessary to punch sex, date of birth, date of entry into service, salary, and, if required, name. That represented about 26 columns, and in such a case anything from one-third to one-half of the punching would be saved. If a computer were used, it could, after punching the full information on the cards, punch out the total benefits and costs by ages in order to produce the statement of costs. He admitted that all that could be done on standard punched-card equipment, but only with a great deal of sorting, i.e. by salary, then by date of birth and then by date of entry, with gang punching from master cards after each sort. There was no point in going into any more detail concerning a group pensions costing, but it would be very simple to prepare a programme for the normal group pension scheme. Whether it would be worth while economically was a different matter. It might prove to be unsound unless the computer could be used continually throughout the year.

That led to a point made by the opener of the discussion when he emphasized the need for a considerable quantity of calculations if the use of a computer was to be justified. It seemed to him that the advantages in the use of those machines lay, not in the complexity of the calculations which they could perform, but in their ability to take two adjacent cards and to perform completely different operations on the data punched in them. That enabled data to be passed through in an order which was most convenient for some other purpose, without interfering with the desired results.

Mention had been made in the past, usually with reference to investment policy, that a life-assurance company was one of the few concerns which provided a long-term contract for a predetermined service at a predetermined charge. Probably one of the most fluctuating and difficult items to assess in an office was that of expense, of which commission and salaries were certainly the two largest components. Commission was, of course, predetermined at the outset, but salaries were, to a very great extent, outside the control of management; if salaries were going up, staff could be reduced to a working minimum, but beyond that there was little that could be done. Staff had to be obtained in a competitive market, and for that reason offices were somewhat at the mercy of any inflation such as that which had been going on over the past twenty or thirty years. It seemed to him that an industry which had that feature to contend with should be one of the first to try to reduce the impact of such a fluctuating factor. In that respect, any machinery which tended to perform the clerical work and the routine work of the office at a price which could be predetermined, i.e. the rental charge or the purchase price, was well worth investigating. Certainly it was not necessary to procure a computer immediately; the first step was to investigate what a computer might do in the office, then to ascertain what characteristics would be required in such a computer, and, thirdly, to find out exactly how such a computer would be used if it were available.

Mr K. Le Cras confessed that he had no practical experience of digital computers, and his only excuse for speaking so early in the discussion was that he hoped to hear the opinions of the many experts present on his views.

Already much had been said about input and output speeds, and he wished to add only two remarks on that aspect. First, there was an American high-speed printer which would write about 1000 lines a minute—something like 6½ times the speed of the punched-card tabulator. Secondly, while the relative slowness of input and output might not be a drawback in many actuarial calculations, such as those cited in the paper, it would seem to be a limiting factor in the use of those machines for routine clerical tasks for which they would otherwise be peculiarly suited by virtue of the principle of setting valves to conducting or non-conducting states in rapid sequence—an operation which could conveniently be labelled 'successive dichotomy'.

The storage unit also appeared to provide scope for further improvement. All the methods of storage then existing had disadvantages which had been partly overcome in certain instances by combining two methods in one machine. For example, the relative slowness of access of the magnetic drum in the Manchester machine had been mitigated by using cathode-ray tubes in conjunction. The latter, however, suffered from the drawback that failure of the electrical power supply caused the information stored in the tube to be erased. That was also the case with supersonic delay lines in which electrical impulses reaching one end of a mercury-filled tube were converted into sound pulses which travelled to the end of the tube at reduced speed and were then reconverted into electrical impulses before commencing their journey all over again.

Those aspects of the hardware had been stressed because it seemed to be important first to know the existing limitations in the development of the machines and, secondly, to realize the possibility of a pre-selected rearrangement of the components to suit the particular purposes for which a machine might be required. In other words, he was advocating 'custom-built' machines as opposed to 'off the peg'—or whatever the American equivalent might be. One user might require speed of computation, as was the case in the early machines which were developed during the war; another might require large storage capacity; and yet another would be more concerned with the properties of automaticity and discrimination. It was those last attributes which he felt, in common with the author, were the biggest advance in the development of those machines and which would probably result in their ultimate widespread use in industry.

Probably most people tended to think of a computer as being primarily a machine for producing a mathematical result and tended to overlook its other possibilities. The presence or absence of an electrical impulse could be used not only to represent binary digits, but could obviously be adapted to any processes involving successive dichotomy, even though they might be anything but mathematical, and that ability foreshadowed the ultimate use of the machines for many clerical tasks.

For example, the apparatus could be adapted to check that all the questions of a completed proposal form had been answered, compare the age next birthday with the date of birth, verify that the sum assured was in line with the age, pass all cases where the questions had been satisfactorily answered, and reject those where the answers were unsatisfactory. The rejects could then be dealt with by manual methods in the ordinary way, or the machine could be arranged to operate some form of numerical rating system which would automatically produce health ratings. Probably many proposal forms would have to be redrafted in order to produce 'Yes' or 'No' answers, but that might not be a bad thing.

The method of feeding in such data would, of course, have to be automatic for such a process to be economic. Punching holes in a card, for example, would be out of the question, and in that sphere it seemed possible that some form of photo-electric scanning process might be developed which could be linked to the computer. Even in the current stage of knowledge it would be possible to use photo-electric scanning to feed in information from a proposal form by drafting the form in such a way that the questions were answered by marking a 'Yes' or a 'No' column. He could foresee, however, that that relatively crude method would be greatly improved in the not too distant future.

That example was, of course, only an isolated instance and ignored the Consolidated Functions Approach. That latter concept of organization could, in his opinion, hardly be over-emphasized in connexion with the machines. Not only would it be important to discard traditional forms of organization, but equally important to question traditional procedures. No longer would Management say 'What does Mr Smith do and how does he do it?' and then try to find a machine to replace him. Rather would the emphasis be on 'Why does Mr Smith do this or that and are his processes really necessary?'. In other words, a large proportion of the clerical processes were a means to an end, and often the intermediate results of those processes had no intrinsic value whatsoever.

Office work that was taking up an increasing amount of time was the production of data for the auditors. Hitherto such data had, in the main, been kept in ledgers in printed form, but it had become permissible to keep the books of a company on cards so long as any particular part of the record in which the auditors were interested could be printed. It remained only to persuade the accountancy profession that magnetic tape or micro-film would suit their purposes equally well. It was obvious that much, if not all, work on those media could be done entirely automatically. The new process would, however, differ radically from the existing one in that a large proportion of the work would be done inside the machine and only essential results would be printed. That system might, incidentally, lead to the discontinuance of what was known as 'double entry'—a process which he had always been led to believe was designed to eliminate *human* error. In its place other forms of control would no doubt be developed, since controls and cross-checks were not only desirable but highly necessary when using mechanical aids. All machines were liable to go wrong, and in the current stage of their development electronic computers were perhaps more subject to errors than most office machines. However, they possessed the big advantage that their speed permitted the use of alternative methods of producing the same answer and so checking the accuracy of their work. He suggested that the golden rule for mechanization should be 'The greater the mechanization the more elaborate the cross-checks'. That dictum, incidentally, did not apply only to the machine. It applied with equal force to the relatively small amount of human control of the machine, a point which was frequently overlooked. The argument that a punched-card machine was operating properly and, therefore, the answer was necessarily right completely overlooked the fact that a human operator had punched the original cards, an operator had fed the pack into the machine and an operator had pressed the switch to start it.

He suggested that not only would each organization using electronic computers find it desirable to build up a library of standard programmes, but that there would also be scope for a central pool of such programmes controlled by the makers of the machines. From such a pool users could be supplied with standard programmes for common jobs, or more probably with prefabricated programme units relating to particular sections of complete processes.

Mr F. H. Spratling thought that binary philosophy and the principles of electronics were highly compatible. Their marriage would clearly produce numerous progeny of varied characteristics. The large computer was one such child. It had attracted more publicity than other members of the family, and although it was a big, quick-witted fellow, in his submission it was still somewhat gawky. It had so far shown more aptitude for science and mathematics than for a commercial career.

Actuaries, and those whose interests lay in the managerial sphere, were principally concerned with the potential application of computers in commerce, and although some of the points had already been made in the discussion, it might be worth while drawing them together and considering in what respects the computers which had already been made required modification and development to meet the needs of commerce.

Scientific calculation generally required a small amount of data to be subjected to a complicated mathematical process. In commercial work a large amount of data had first to be prepared and mobilized and then submitted to simple arithmetical processes. The results of commercial arithmetic and office procedures must be thrown up in a form which could be understood by the many. In short, they must be readable, capable of arrangement in any reasonably required order, and often permanent in form. In scientific work it did not greatly matter if results were thrown up in an ephemeral form, capable of being understood only by the initiated few.

The logic of mathematical processes was pure. The logic of commercial procedures was complicated. However severely standardized a commercial procedure might be, it had to allow in the last analysis for the oddities of human behaviour. A competent clerk could quickly recognize the exceptional case and adapt himself to its particular circumstances. The machine must be instructed to apply a set of tests, one after another, to each case until its characteristics were exactly defined in terms with which the machine could deal. Commercial work often had to be undertaken within the limits of an exacting time-table. In scientific work the time-table might be less compelling.

In those various respects, the antithesis between science and commerce was sharp and strong. With those contrasts in mind, it was possible to be more specific, though still in general terms, about the desirable characteristics of a commercial computer.

Considering the implications of mobilizing a large amount of data and submitting it to simple arithmetical processes, it was necessary first to analyse the work of the office to discover how much time, or how little, was spent on computing. A large computer could do as much calculation as scores, or even hundreds, of clerks, but there could be few organizations where the volume of computing was equivalent to whole-time employment for a really substantial number of people. By far the larger part of the work was devoted to preparing and mobilizing the basic data and producing the papers—bills, renewal notices, proof sheets, and so on—required for the day-to-day business of the organization.

It followed that a large and expensive machine could rarely be justified if its function were limited to the computing work of a single commercial organization. An expensive machine would earn its keep only if it could shoulder some part of the burden of record making, before and after calculation, although the enormous potential of the computer in its own field might, of course, justify more routine calculation than was usually thought necessary. In technical jargon, effective solutions must be found to the problems of input and output. It was good to know that they were being studied intensively in several quarters. The alternative was to continue to use existing methods for the work which preceded and followed calculation, in association with electronic devices for the calculations themselves. The economics of that approach required the computer to be relatively inexpensive. Cost would presumably have to be kept down by limiting the capacity of the machine to the performance of a simple programme.

The next contrast was between the purity of mathematical logic and the impurity of commercial procedures. Large electronic computers had shown themselves to be well-adapted to mathematical and scientific computations. They could also deal with commercial calculations, but at the cost of complicated programming. Even with electronic speeds of working, an appreciable time could be spent on a single commercial calculation which to a clerk would seem relatively straightforward, although involving the exercise of judgment. After allowing for the relatively complicated programming, the speed of output from the computer might approximate to, or even be less than, the speed at which a known device could record the output. In such circumstances the economics of the large computer were dubious.

Again, it was tempting to think in terms of breaking the work down into stages at points where judgment had to be exercised, and then relying on simple and cheaper machines to perform the intermediate steps of calculation, one at a time.

The question of fitting the work into a rigid time-table would frequently be exacting in commercial work, and that brought the administrator face to face with the question 'Dare I rely on a single machine?' (He was indebted to a friend for pointing out that a faulty computer provided the fastest known way of wasting time!) The administrator's answer to the question must often be 'No! I must have two machines', and the economic implications of that answer were obvious.

There was no doubt that electronic computers were destined to play a large part in commerce, but whether the future lay with the larger machines, developed and modified in some such ways as those to which he had referred, or with smaller, less expensive machines, was not yet resolved.

Mr T. Whitwell said that the author had presented to the profession a compilation which would certainly be widely read. There had been a need for such a paper as the one under discussion, and that need had shown itself in other places, educational establishments and so forth.

There was also a need, as had been experienced in the United States, for continued consideration of those problems by the profession itself, and he hoped that the meeting that night would be but the first of many similar meetings to be held as knowledge of the art grew.

He was indeed pleased to see that the author had given credit to a member of the profession for earlier work in connexion with such machines. It was equally pleasing to see that he had not followed the prevalent practice of crediting the authorship of such machines to Babbage, who committed the heinous sin of spending large sums of money—much of it public money—without producing a machine which was saleable or even properly workable. Babbage was, in fact, forestalled by the philosopher Leibnitz, who produced a machine which was exhibited in London and Paris. Leibnitz later received the Fellowship of the Royal Society, but very little notice had been taken of his work. His machine was extremely advanced for that date and was capable of performing the four rules of arithmetic, extracting square roots and so on, automatically, and perhaps someone might be interested to pursue the historical aspect of the matter a little further back than had been done in all cases where Babbage had received so much credit. It would also be found that Pascal had invented the adding machine even earlier, and the fact would also emerge that he invented a machine which was equally useful, namely, the wheelbarrow!

When he received the paper he turned first to the example with which the author had chosen to illustrate the potential use of the large-scale digital computer in the actuarial profession, and he was rather disappointed. In his view the calculation of loan schedules was peculiarly unfitted to large-scale digital computers in the hands of actuaries. He believed that the young men in the profession should learn the hard way by grinding those things out on calculating machines. They should be given the privilege of enjoyment when they obtained the right answers. It also gave them the legitimate opportunity of indulging in the use of large numbers of spurious decimals!

The quotation from Phillips's paper also fell short of illustrating the true requirements of the profession. Phillips spoke of doing valuations whilst at lunch on 1 January. That was all very well, but there were at least 364 other days in the year, and on those days people were being born, dying, filling up proposal forms, and so forth, and that was also the concern of the actuary. Whether the machines could deal satisfactorily with the type of work which actuaries as business men had to handle required much thought. The author's example of loan repayment schedules involved a small amount of input, a relatively substantial amount of calculating, and a modest amount of output. The day-to-day business of actuaries was quite the opposite. It involved a great amount of input of a very mixed kind, a modest amount of calculating and a considerable amount of output. Those conditions were almost diametrically opposed to the ideal conditions for the use of the large-scale computer.

He did not desire to give the impression that in his view there was no future in actuarial work for machines using electronic principles. That was certainly not so. The actuary would find it significant that the first machine which was produced under the auspices of the National Research and Development Corporation, Lord Halsbury's organization, was priced at something like £80,000. That organization had sponsored another machine only recently produced—it was for that reason not mentioned in the paper—which was priced at about £30,000. Following that curve along the same time-scale, it was not unreasonable to think that within a year or so there would be a machine at £15,000 or possibly even less than £10,000.

Certain individuals, not the author, had indulged in forecasts which implied even more all-embracing machines and even more widespread uses for them. The speaker preferred to see a decreasing size and complexity in future machines which would, of course, render them all the more available to the profession.

A point that should not be overlooked was the very considerable amount of ancillary equipment needed to service the large-scale digital computer. Present at the meeting were some visitors who had carried out most meritorious work in investigating the possibility of using a large-scale digital computer for handling purely clerical work, and they would probably admit that there was a considerable volume of ancillary equipment which in their organization had been allotted floor space almost equal to that taken by the computer itself in order to translate the basic data, which, in life-office work, would be proposals, death certificates and the like, into a form suitable for handling by the computer. That information had to be transformed by human agency into paper tape or magnetic tape or some similar input medium. It had to be done twice by two independent human operators, and mechanism had to be provided to compare results. That ancillary equipment could be as troublesome in its design and operation as the main computer itself. The scale of the whole operation had to be reduced to something more manageable if computers were to be handled by insurance officials.

He also felt that there was room for much more development of the 'memory' of the machines. The computer was not like a human being with vast memory and accumulated experience at his or her command. The human being also had discretion, but in machines all that had to be replaced by mechanical or electronic memories. The complexity of working of the large-scale machines could be illustrated by the case where the Manchester machine was set to play a game of chess. A 'mate-in-two' problem that would be solved by a good chess player in a matter of seconds, would probably take 15–20 minutes to solve on the Manchester machine because the machine had to examine every possibility, however absurd, before it could find the solution. The question of 'memory' and 'experience' was therefore one which was at the root of much of that which would have to be considered if the machines were to take the place of human agencies.

The bulk of the memory used in life offices at the time of speaking was in the form of holes in cards. That form of memory was permanent. It could record the particulars of policies accurately and precisely for 50 years. That form of memory would be difficult to replace, particularly because it was so easy with memory in a discrete form such as punched cards to change it, by removing the offs and introducing the ons, a problem not so easily resolved if the memory were in the form of invisible impressions on continuous tape.

Mr C. D. Sharp considered that a little practice was worth a great deal of theory, and drew attention to the fact that both in America and in the United Kingdom those with practical experience of the electronic computer favoured the idea of experiments to investigate the saving which could be achieved in clerical work if electronic equipment were introduced.

Reference had been made in the paper to the successful practical application of the computer in calculating the new Institute Annuity Tables, and he would like to mention another experiment which had been carried out by the Societies with which he was associated. That consisted of a simple gross premium valuation of some 28,000 policies using the computer at the National Physical Laboratory at Teddington. The data were supplied to the computer in the form of punched cards, representing the six main classes of policy, namely,

Whole Life with and without profits,
Endowment Assurances with and without profits,
and Whole Life Limited Payment with and without profits.

In some cases the policies were valued in groups and in others they were dealt with individually. The results of the experiment were interesting but inconclusive, since in practice the computer would not be used solely for an operation of that kind. The main advantages to be obtained from the use of electronic equipment lay in the facility for switching rapidly from one type of operation to another, and because of the limited storage capacity of the calculators then available those advantages could not be used to the full. The high speed of calculation was not of importance for a straightforward valuation, although it could be useful if valuations had to be made on alternative bases. That might become of much greater importance if the restricted worth of valuations at a single rate of interest were to be more generally recognized. The experimental valuation on the computer did provide an opportunity to see the equipment in action, to appreciate the complexity of programming and to discuss the more immediate possibilities.

Turning to the more general aspects of the matter, he considered that just as punched-card equipment had largely revolutionized the preparation and handling of data in the larger insurance companies over the last 25 years, so electronic equipment would change the status of clerical labour during the next decade. That type of equipment could be designed to perform all the functions currently carried out on standard punched-card equipment, and in addition could take over a good deal of routine clerical work. If the cost of electronic equipment were materially reduced, as seemed probable, then it would become economic to eliminate much of the existing punched-card equipment, and companies would be able to take advantage of the additional facilities afforded by the computer. With the continuous growth in salaries and overheads considerable advantages were to be obtained from mechanization if it enabled existing staff to handle a substantially increased volume of business.

Another interesting possibility was that of extending the scope of the profession. If it were true that in the not so distant future there would be wide fields for the application of those new conceptions it could provide the younger members of the Institute with an excellent opportunity for moving out of insurance into industry and commerce. He supported the suggestion made by the opener for some central organization to be set up to study the problems so that members of the Institute could play their part in the developments which, in his view, were certain to take place. An organization of that kind would also make it possible to teach students to think more about office organization and methods and to study the conditions in which it would be economic to take advantage of the wide capabilities of the new types of equipment.

A point had been made in the discussion that the computers were liable to error. That was true of any manual or mechanical system, but the electronic computer had the virtue that periodically it would check itself. In one investigation where the electronic computer had been used in parallel with an existing system the only errors found during a test period of six weeks had occurred in the results obtained by the conventional methods. At the end of the six weeks the whole investigation had been passed over to the computer, and the previous system had been abandoned.

Mr T. R. Thompson (a visitor) said that he joined in the discussion because of his knowledge of operating a computer (LEO), and such practical experience taught more about the subject than any other kind of study.

He did not want to exaggerate the progress that had been made. He liked to think of the project as being similar to the first aeroplane that flew across the Channel. Although that flight was successful it could not be followed immediately by a regular air service across the Channel. That required a great deal of operational and technical research. He considered that electronic computers had reached a stage analogous to that flight of the aeroplane across the Channel.

The first question in which people were doubtless interested was that of reliability. Reliability at the time of speaking was not by any means adequate for commercial jobs. Nevertheless, much that was needed to make the machines reliable was being learned.

The other factor to which he ought to refer was the question of input and output. Personally, he did not regard that problem as a problem at all in the theoretical sense. It was purely and simply one of reliability. That problem had been studied in the Lyons Electronic Office since 1947, and since 1949 practical steps had been taken to make high-speed input and output systems which would cater for input and output at the same speeds. For some months prototype equipment had been working in the organization, and it had reached the stage where consideration could be given to doing work with it. There was no question about the speed. The question was one of reliability, as it was with the remainder of the equipment.

Reference was made to the area occupied by auxiliary equipment for feeding in and out. Again that was a phase in the development period when data had to be transcribed into a form suitable for feeding to the calculator. One speaker talked about using one of the proposal forms for scanning. In his view that would come about and could be operational within the next five years provided the necessary development work was done.

It was not his concern whether the Institute, or insurance companies, would adopt the machine, but it would take a long time to develop the arrangements for using the computer in insurance work. Steps could be taken immediately not only by way of study but by carrying out experiments in programming jobs and trying them out. He felt personally that within the next ten years insurance companies would undoubtedly start to use the machines first on a small scale and then on a larger scale.

Dr F. Bowden (a visitor) desired to supplement Mr Thompson's remarks, and the first thing he would emphasize was that existing machines were designed to do pure mathematical work only. It was a remarkable tribute to the versatile nature of the machines that they could be adapted to carrying out work of a type for which they were never considered to be suitable when first built. They were, after all, first designed only a matter of some half a dozen years ago, and in the enthusiasm for them it was easy to overlook that fact and easy in retrospect to criticize the designers.

The second point was that it was much more difficult than would be imagined before the attempt had been made to get programmes right and to obtain a general understanding of how a problem could be put to the machine. He had found that it was more difficult to do ordinary programming for the valuation of a policy than to solve a complicated problem in simultaneous differential equations, the reason being that mathematical equations, once they had been formulated, were fairly straightforward, whereas any commercial problem was subject to discontinuities imposed by Acts of Parliament and these had to be put into the machine. Without unduly criticizing the lawmakers for being illogical, he found it difficult at times to believe that they were motivated by anything other than pure spite!

He urged on those present that they could only understand what sort of problems were suitable for solving on the machine by going into the matter in detail and finding out in practice how the difficulties should be tackled. He had with him the results of a study which had been made in Canada recently of the way in which certain problems could in fact be solved on the computer that was at the moment engaged on working out the flow of water of a river. That illustrated that the machine was capable of application to a variety of problems, but it was unreasonable to think that it should be suitable for all problems. In the life-assurance case referred to the problem was to deal with a million policies a month, keep them up to date when changes had to be made, prepare premiums before they fell due and make cash calculations. The calculations involved in handling each policy, according to an estimate which had been made, could be done in a few seconds, but the speed of the input and output was not sufficient to keep up with it. That presented no fundamental difficulty in principle, and it seemed to him that it was almost certain that the necessary equipment would be available before very long.

The type of problem which was suitable for the machine was by no means obvious. The answer could only be discovered by regular survey, and he urged members to remember that the organization of their own offices had been growing up stage by stage after great labour on the part of those responsible over a period of many years, perhaps even centuries. It would take several years to effect the changes necessary before the work could be given to a computer (which could be described as infallible yet imbecilic in behaviour). It was a difficult and laborious job, and one which would tax the ingenuity of organizations and the actuarial profession for a long time to come. But the promise was there, and it would be tragic if the profession were to delay tackling that difficult job on the assumption that better machines would be available before long.

Mr H. A. R. Barnett had discussed the paper a few days previously with a psychologist who was also a statistician. At one time that gentleman had been attached to one of the universities, and had participated in a game which involved teasing one of these machines by inducing what he, in psychological terms, called an 'anxiety state' by giving it a series of incompatible instructions.

Referring to § 71 he said that about two years previously a member of the Institute submitted a problem to one of the organizations that had an electronic machine, and received the reply that the machine could not make a minimum-χ^2 fit. He did not know whether that was still the position, but he would have thought that a suitable programme could have been drawn up, although minimum χ^2 was a problem which might induce an anxiety state in the programmers!

Mr T. B. Boss said that it might be of interest if he commented briefly on the other machine working in the London area—the machine at the National Physical Laboratory. In view of the remarks made earlier concerning storage capacity, it might be as well to make it clear that the machine was definitely a small prototype designed to obtain working experience. It was hoped to attach a magnetic drum that summer, and it was hoped to have a second similar machine working the following year; i.e. a machine with a small high-speed memory and a moderate-sized slower magnetic-drum memory.

For the time being they had refrained from pursuing the design of the large machine intended when the project started. The remarks about cost had elucidated the position a little. The feeling based on the work which was done at the National Physical Laboratory, and which was almost entirely mathematical, was that the moderate-sized machine, the cost of which it would appear was becoming reasonable, was capable of doing a great deal of work.

It was possible to show a few members of the Institute who visited Teddington the small demonstration, already referred to, of an actuarial valuation. That showed very clearly, in the relatively small amount of time which had been devoted to organizing it, that the equipment there was inadequate, in two respects. The first was its input and output speed; the second that they were not organized to do sorting as understood in punched-card language.

On general working experience, he desired to misquote slightly a remark made shortly after the war of an internationally large computing organization and say that the effect of having such a machine was to change the whole outlook on life; in his view those concerned would never again be happy without one!

The problems of checking were difficult, and the economics were dependent upon the proportion of the total effort which was expended on arithmetic alone. But in his view the great power, the speed and the economic costs of the work which could be done, coupled with the satisfactory reliability of the machine, called for a slightly greater feeling of optimism than was his own reaction to reading the Report of the Society of Actuaries. He felt that the implication—possibly not intended—was that a need for planning undoubtedly existed, but that there was time in which it could be done. In his view there was not too much time, because the moves in the United Kingdom in the immediate future were dependent in part on the demand for particular gear, and that demand had to come partly from possible users. The staff at Teddington was concerned at that moment almost exclusively in mathematical work, but it was the function of the Department to which the N.P.L. belonged to interest itself in rather wider matters; and he desired to endorse very strongly indeed, on the basis of working experience and some considerations which had been put forward admirably by previous speakers, the need for a co-operative effort to meet what was bound to be the heavy cost of developing some of the necessary equipment in a reasonable and practicable time.

Mr R. E. Beard referred to three points pertinent to the paper about which nothing had been heard at the meeting. First, some of the principles which were coming to light when applying electronic digital computers to actuarial work were put forward at a sessional meeting in 1941 at which the differential analyser was discussed (*J.I.A.* LXXI, 193).

Secondly, many of the advantages of the Consolidated Functions Approach had nothing to do with the electronic computer at all, but arose from cold analysis of office routine and elimination of unnecessary work. That was an important point, and it was necessary to exercise care in seeing that office routine was efficient relative to the machines available. Until the routine was efficiently organized—and it required a fairly ruthless approach to achieve that—the end-result would be disappointing.

Thirdly, if the office were large and employed some hundreds of people, a change of routine in order to take advantage of the electronic computer entailed doing something about the staff. It could not be changed over-night, and quite a proportion would not be amenable to radically different routine methods. That was one of the bigger difficulties to be faced in taking advantage of the opportunities offered by the new machines.

Mr G. W. Pingstone considered that the problem of maintenance had not received the emphasis which it should have done in the discussion that evening. His personal experience of electronic equipment that might be considered the forerunner of the electronic digital computer led him to feel that where thermionic valves were employed the likelihood of breakdown was considerably greater than with purely mechanical or normal electrical-type devices.

There was little doubt that in meeting that maintenance problem it was of considerable assistance if the equipment was constructed in the form of readily interchangeable units, and he would ask that the designers of electronic digital computers should keep the point well in mind, since a machine which could not be kept in operation continuously would lose much of its value.

In concluding his remarks he wished to ask the author whether he could give an indication of what effect the advent of transistors was likely to have on the design and cost of the type of computer under consideration.

Mr William Phillips, in closing the discussion, said that a man went into a chemist's shop and asked for 16 grains of quinine. The girl behind the counter weighed up something from a bottle, mixed it in a glass, and he drank it. 'How much?' said the man. 'Oh,' said the girl, 'I think I have made a mistake. You asked for quinine didn't you? I've given you strychnine.' 'Well, it tasted bitter,' said the man, 'is there any difference?' 'Yes,' said the girl, 'fivepence'!

There had been a number of meetings since 1946 dealing with high-speed computers, but he thought that evening's meeting was the first at which the word 'electronic' had been included in the title. He felt that the author should not have limited them to electronic computers without explaining that there was a difference of more than mere price between electronics and electrostatics, and without explaining why he excluded electrochemical computing elements. For example, it was well known that the interfacial tension between mercury and an electrolyte was strongly dependent upon the potential difference between them, and the device used in capillary electrometers might be extended to serve as a single-pole, double-throw, voltage-actuated relay, whose time of response was less than 1 millisecond. Perhaps the life offices, more concerned with daily reliability than with ultra-high speed, would eventually employ electrochemical computers.

He was particularly pleased to have been invited to close the discussion on a paper which had provided so useful, so compact, and so bright a summary of a subject, the bibliography of which now ran into many hundred items. He was perhaps in as favourable a position as most to assess the difficulty of the task the author had undertaken, and to appreciate the skill with which he had accomplished it.

Since the author had referred to 1936, the speaker would like him to reconsider §§ 2 and 3. In § 2 where he said that it was unlikely that in 1936 anyone expected a high-speed binary computer to operate within ten years, the speaker felt that he must have excepted himself for one! But he also challenged the assumption at least on behalf of those no longer alive. There was the speaker's father, who worked on the 1936 project from 1934 until his death in 1938; there was the then President of the Institute, C. R. V. Coutts, who took the responsibility of accepting the paper, and announcing it at the previous session, before it was written! That was because the project had been offered to the government, and they were rather in the government's hands; and there was the late Rt. Hon. C. A. McCurdy, P.C., one of two people who sponsored the offer to H.M. Government, and secured its acceptance.

In that connexion he desired particularly to mention Mr Oakley of the Dep rtment of Scientific and Industrial Research, whose duty did not require him to do more than receive the specification and file it, and who instead spent three months in close touch with the speaker and gave him valuable help.

He was grateful to the President for his remarks about continuity. On reading § 3 the uninitiated might imagine there had been some kind of hiatus, whereas in fact there had been no pause in the endeavour to develop high-speed computing machines since 1934. Soon after the Institute meeting in 1936, Turing read a mathematical paper on work which could be done by such machines if they existed and, thus inspired, Womersley set to work on their design early in 1937, and by 1938 Norfolk was working with him. Womersley and the speaker were in touch by early 1943, Womersley read a paper to the National Physical Laboratory in 1944, and by 1945 he and Turing had got together. 21 March 1946 was an interesting date; that evening Womersley gave a paper at the London Mathematical Society on the ACE project then under construction, the first of the binary computers, and so far as he knew the first public discussion of electronic computers since the Institute meeting of 1936.

It was a pity that by limiting himself to electronic machines the author had not been able to mention the Harvard IBM Model I. It was designed in 1937 and finished in 1944. It had been described as 'Babbage's dream come true', and Hartree had used it in his book in building up an explanation of electronic machines.*

In July 1834 Dr Laidler wrote a description of Babbage's difference engine in the *Edinburgh Review*, and in 1855 two Swedes, the Scheutz father and son, won a gold medal at the Paris Exhibition for a machine constructed by them on the lines of Babbage's machine.† It was demonstrated in the United Kingdom, and was so successful that one was built in London by Donkin for the General Register Office.‡

In connexion with the Institute Centenary in 1948 there was an historical exhibition which included parts of Babbage's analytical engine; but there was a strange omission from that Exhibition, namely, the two volumes of the English Life Table No. 3, which was calculated on the Donkin-Scheutz-Babbage machine. The first volume contained a description by Dr Farr of the machine, and of the way in which it was used; in his view some of it might well be reprinted in the *Journal.*

It was gratifying to note that the author would have nothing to do with the 'giant brain' nonsense. Lady Lovelace said in writing about Babbage's machines over a hundred years previously: 'The Analytical Engine has no pretensions whatever to *originate* anything. It can do whatever *we know how to order it* to perform' (her italics).§

Although no machine had a brain, a brain was very like a binary calculator in the sense that every neuron had an 'all-or-none' response. McCulloch, the psychiatrist, on the basis of matching neurons in the animal brain against

* It should be borne in mind, if only to avoid confusing it with the Harvard IBM Mark II of 1947, and the Mark III of 1949, which are, of course, electronic.

† It was purchased by a wealthy American and presented to the Dudley Observatory, Albany.

‡ It consisted of some 4000 pieces and weighed about 10 cwt. The Harvard IBM Mark I weighs over four tons, consists of more than three-quarters of a million parts, and incorporates 530 miles of wire.

§ The journalistic nonsense about 'giant brains' is a little older than some suppose. A respectable newspaper headed an article 'Machines That Think' as early as February 1937.

flip-flop valves, had pointed out that the largest and most expensive computing machine so far made had about as much brain as a flat-worm, and that a machine with as much brain as a village idiot would require for its operation all the power of Niagara, and to keep it cool all the water which flowed over Niagara Falls! McCulloch and Pitts designed in 1943 a symbolic system for analysing the operation of the nervous system; Von Neumann adopted that system for analysing the operation of computing machines; Turing and Hartree extended it. It was the system used by the author.

But it was a matter of personal regret to the speaker that the author did not follow Shannon, as Hartree did, in using the symbolism of mathematical logic which they owed to George Boole's *The Laws of Thought* of 1854. He expected to see Boolean algebra included in the syllabus of their examinations ere long; the student would be relieved to learn that it had been described as being simpler than arithmetic.

It was pleasing also to note that the author emphasized simplicity as compared with speed. It was not much use having a machine that could do three-quarters of an hour's work in three-quarters of a second if it took three-quarters of a day to set it up. One day a lady went into a shop and said she wanted a toy for her small son, but that it had to be instructional. 'Yes, Madam,' said the assistant, 'here we have the very thing. It is specially designed to condition the young lad for the world in which he will have to live. Whatever way he puts it together it won't work.'! He felt sure the life office would be better off with a machine that dealt in milliseconds and worked, than with a machine that dealt in microseconds and broke down.

It had been interesting during the past seventeen years to see whether human ingenuity would get the machine past the binary stage to the decimal before the human mind adapted itself to thinking in the scale of eight. There were at the time of speaking two machines with an octal input, the BINAC and the IBM 701. There was also an optional octal output available.*

A factor which might influence the future trend was the principle of the Grosdorf counter as applied to computers. Four trigger circuits in a sequence would normally constitute a counter with a modulus of 16. However, Grosdorf had shown in 1946 that such a four-stage binary counter could be made to skip 6 states, and so become a decimal counter.

Their American actuarial colleagues had had five years' start over them. At a general convention at Harvard in 1949, which lasted a week, 300 people were expected but 700 attended. He felt sure the author did not expect the discussion to finish in one night on a subject so vast.

The President said that more than one novelty had been introduced into their proceedings that evening, and he thought it was an appropriate sign that the Institute, without loss of dignity, could move with the times.

He desired first of all to express the Institute's indebtedness to the electronic computer, since the Institute's and the Faculty's new annuity tables had

* Hartree has said: 'It is rash to make guesses about future progress—or, anyway to proclaim them; but my own guess is that the use of the binary system...is a passing phase.... I am fully aware, though, that others whose opinions I respect dissent from this view.' Finelli reports that Dr Alexander, of the National Bureau of Standards, reasons that since a pure binary computer might require only two-thirds the equipment of a decimal computer, any new computers developed should be binary machines.

recently been calculated with its help. He wished particularly to express their appreciation to those of the guests who had afforded help in that matter.

Several speakers had commented on the necessity of members of the actuarial profession keeping in touch with those who were experts on electronic computers. Indeed, that thought must have been in everyone's mind, particularly when it was learned how promptly the Society of Actuaries in the United States had interested itself in that important problem. He assured all speakers who had mentioned the matter that their remarks would be carefully noted.

He imagined that most of those who had entered the Hall had the impression that in one form or another, larger or smaller, electronic computers must, before many years were passed, render a powerful aid to members, whether in their capacities as actuaries to life offices, or possibly as actuaries in other forms of endeavour. At the same time the definite impression was probably gained that caution would have to be exercised in adopting and adapting the machines to their work. Probably particular caution was felt in regard to the matter of input and output, and on that aspect of the problem members would have been heartened by the remarks which Mr Thompson made out of his practical experience. However, it should always be remembered that the problems of a life office started with a proposal form upon which there were written words and figures and finished with a receipt upon which there were also written words and figures.

It was no criticism of the paper to say that not everyone present would have understood every sentence and every paragraph in it. For himself, he was ready to take as an act of faith, as the author suggested, the parts which he was unable fully to comprehend. As a complete layman in the matters discussed, he felt that the author had expounded the subject with a high degree of lucidity.

He was a little frightened, not of the speed of computers of the future, but of the consequences of that speed. It was a few years now since he was responsible for conducting a life-office valuation and signing a valuation report, but he had the clearest recollection of the great advantage of a considerable period of relaxation during which he could compose his mind for the problems to come while many other people were busy producing the results! It was important that time for relaxation and composure was still retained and that care was taken to see, as and when the computers became available, that they gave not less time for thought but more time for thought. Although the users would remain consciously masters of the machines in point of performance, there might be an insidious danger of the users becoming less consciously their servants in point of time.

Everyone present would feel grateful to the author for his paper, for bringing the subject so interestingly to their notice and for stimulating such a good discussion, with more speakers than he could remember for quite a while.

Mr R. L. Michaelson, in reply, expressed gratitude for the reception accorded to his paper and for the most stimulating discussion. He would not say that he agreed with everything that had been said, but he did not propose to reply to much of the criticism for the evening was rapidly drawing to a close. However, there were a few heavy guns fired and perhaps he might reply to those.

Mr Leapman suggested that he was being over-optimistic when he said that the supervisor of a punched-card installation could continue to do the same work on a computer. He still adhered to that view, but emphasized that he meant a good supervisor. Some supervisors who were not really efficient at the job they were doing on a punched-card installation could make a worse mess of things on a computer.

Mr Leapman also suggested that group life and pension business could be used as a good testing ground for electronic computers in life offices, and he certainly agreed with him. He did not think, however, that Mr Leapman was right when he implied that the amount of hand punching would be reduced because there was a computer. He could imagine that it would be possible to make the calculations Mr Leapman described on standard punched-card machines, though it would involve a large amount of sorting and the use of auxiliary machines as explained by Mr Leapman.

He felt that there might be danger in the investigation that Mr Le Cras described to decide whether Mr Smith's process was really necessary. Perhaps so many Mr Smiths with so many unnecessary processes would be found, that the volume of work would drop below that at which even conventional punched-card machines were economical!

Mr Whitwell criticized the example which he chose to illustrate programming methods. He accepted his criticism but pointed out that it was quite impossible in the confines of the space allowed to take a larger problem or one involving commercial logic rather than mathematical logic. He agreed with Mr Whitwell that other people's visions of bigger, more complex and more embracing machines might not be fulfilled. The immediate future would certainly be better served by the production of smaller and cheaper machines.

He had a feeling of guilt because he had quoted Mr Phillips without first asking his permission. However, he was unrepentant because, had that permission been withheld, it might have been that the Institute would have been denied his most interesting, stimulating and apt remarks; he was glad that he had not come between the members of the Institute and those remarks of Mr Phillips.

Mr Kermit Lang, F.S.A., writes:

The feature which distinguishes any electronic computer from an electrical relay or desk-model type of calculator is, of course, the fact that the electronic machine is actuated by a train of electronic impulses rather than by a rotating shaft. Thus the electronic computers are closely related to the type of light-ray machine which William Phillips had in mind in 1936, but bear little resemblance to the machine which Charles Babbage envisaged in his lifetime. This is certainly no reflexion on the ingenuity of Babbage's invention, because even the electric motor, as we know it, was not invented until 1873, two years after Babbage's death, and the electronic flip-flop circuit was not discovered until 1919.

In the light of American experience it would seem that a very compact and not too expensive electronic computer could be built which would fulfil a widespread demand in Great Britain. I believe this new machine should be a computer and a punch as well. For a large variety of office work, punched-card output is essential. Printed results are not required or desired until after some subsequent sorting or other operation.

Perhaps the best summary of the state of development of electronic devices in the United States and their probable effects on insurance offices is contained in the introduction to a recent article entitled 'Why Wait for Electronics?' by

Joseph W. Hughes, Vice President of the Insurance Accounting and Statistical Association:

Much has been written and discussed in recent years about electronic machines and how they will affect the operations in an insurance office. Many well informed people are very optimistic, while others are equally pessimistic about these devices.

The machines that most people think about when the word electronics is mentioned are those super information-handling machines that are still in the laboratory. Some of them have been tested, but none is in use to-day [written in January 1953] in the insurance business. All seem to evolve around the use of magnetic tapes on which information is stored in a very small area. These tapes can be corrected and changed without manual look-up and filing. They have the ability to be processed at very high speeds for any desired results, either numeric or alphabetic. No one really knows the full extent to which electronics can be applied in the insurance office.

Even with these machines, we must always have documents to go between the office and the policyholder, between the Home Office and the Branch Office, for individual changes and individual accounting entries. Therefore, the punched card must always be used as the intermediary document. It is the 'go between' for the daily operations and the high speed electronic accounting machines.

Mr Michaelson has put forward the view that the management of any large organization will be able to preserve its competitive position only if it makes full use of electronic office aids. American executives will subscribe to that view, but may ruefully shake their heads and say that it is not so much that they have been or will be hard pressed by their competitors as it is the pressure of the inexorable march of events which has forced this view upon them. At least four contributing factors can be suggested offhand.

There is first of all the growth in size and complexity of our business which has forced us to seek far-reaching new methods and devices to bring the enormous detail of our operations once again within compass. As we expand our operations into new fields and take on new risks, we must seek to analyse the experience as it emerges, within days and weeks, not months and years. At the very same time we are faced with the twin spectres of steadily rising wage costs and a growing shortage of man-power. Clearly, then, we must resort to more mechanization, we must put more tools into the hands of our staff, if we are to maintain the quality of our product and our service.

Therefore it is evident that the potential applications of electronic computers and other office equipment employing the principles of electronics is of great interest to actuaries and other life-insurance company executives, in the United States and Great Britain alike. Mr Michaelson has laid the groundwork for such a study in very able fashion by figuratively taking the covers off the machines.

Mr R. L. Michaelson has written as follows in amplification of his reply to the discussion:

Mr Ramm, in opening the discussion, made good many of the omissions in the paper. With most of his points I agree, but I believe he greatly overstates the case for magnetic tape at its present stage of development when he suggests that it feeds at some fifty times the speed of punched cards. 80-column cards fed at 150 per minute, which is an everyday occurrence, is an input of 200 denary (or duodenary) digits per second. If the card is divided into two fields of 40 columns and 12 binary numbers punched in each field then the input speed is 60 numbers of 40 binary digits each per second or 2400 binary digits per second. This system I understand is in use in North America and gives speeds of the same order and perhaps actually higher than magnetic tape. The parallel input offers speed advantages at the cost of extra hardware. The basic card-fed speed of 150 per minute can be improved. ACE already has a feed working at 200 per minute and accommodates 12 numbers of 32 binary digits each per card, thus achieving an input rate of 1280 binary digits per second. These are some quantitative reasons for assuming that punched cards will continue to play an important role in office work. Mr Whitwell has stated some of the qualitative reasons.

The speed quoted by Mr Le Cras of 200 characters per second applies only when the input is punched in binary. It is then equivalent to 1000 binary digits per second as he states. If a row of five characters represents a denary digit then, I understand, the time taken on the computer to convert to binary before a number can be stored is greater than the interval between digits. Consequently the feed does not then operate at its maximum speed. This bears out Mr Thompson's remark that input is no longer a theoretical problem.

I am particularly pleased that Mr Phillips has recorded the names of some of his associates who were responsible for the first and therefore hardest steps.

The restriction to electronic machines which Mr Phillips mentions was imposed by consideration of space as well as inclination. Rightly or wrongly I believe that mechanical analogies do not make the electronics any easier to understand, but I do regret that I was prevented from paying tribute to the pioneer work at Harvard.

A study of the discussion reveals that many of the remarks of the later speakers are complementary to many of the remarks made earlier. In this connexion I am especially grateful to Messrs Thompson and Boss.

The subject is so fluid that little purpose would be served by attempting to comment on each point made in the discussion. It appears, as many speakers suggested, that the right course at the present time is actively to study the potentialities of these new calculating aids and to make as many practical experiments as possible.