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CALCULATING DEVICES AND ACTUARIAL WORK

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ABSTRACT

This paper is the report of a Research Group which has been examining developments in calculating devices, the effects on actuarial work and the future outlook.

1. DESK CALCULATING DEVICES

Introduction

1.1 The purpose of this section is to provide an outline of the development, from about 1600 to the present time, of desk devices which were available to assist a calculator. By a 'calculator' we mean a person engaged in calculation, and we have taken the term 'devices' in a wide sense, to cover not only machines used by a calculator, but also tables, especially logarithms. We have, however, excluded from this section devices such as the desk-top terminal of a large electronic computer.

1.2 Clearly, such an outline must of necessity be very compressed, and cannot do justice to a fascinating story of continuous development; but it will, we hope, establish a background against which we can consider the enormous changes of the last 40 years, and the equally great changes which lie ahead.

1.3 We must also add that the outline is based on published work, and has no claims to be original research.

Calculation in 1600

1.4 In 1600 astronomy and navigation were highly developed sciences with established techniques. Double-entry bookkeeping and interest calculations, including compound interest, were also well known. But the practitioners in these subjects did not have many devices to help them in the actual calculations which their work entailed. The Chinese abacus, the earliest desk machine, had been well known in Europe in the Middle Ages, but by 1600 it was no longer used in Western Europe—although its use in Eastern Europe and Asia has continued to the present day. (The Japanese abacus, with four beads above the bar and one below it, was purchased by several actuaries at the Japanese Congress.) A few elementary compound interest tables had been published in Europe by 1600, but it was probably the case that all forms of multiplication were heavy pen-and-ink jobs.

Advances in the Seventeenth Century

1.5 The seventeenth century saw many great developments, both in devices to assist in calculation and in ways in which calculation could be used. Thus we have in the invention of logarithms a device which greatly reduces the burden of multiplication and division, and in the development of probability theory we have a subject which makes use of the new calculating power which had come with logarithms. In particular the practical development of the life table, and with it the practical use of life-contingency theory, would not have been possible without logarithms. The seventeenth century also saw the first stages in the development of machines which would assist in calculation. Their immediate impact on calculation was far less than that of logarithms, but they were the first step in developments which were to bring great changes.

Logarithms

1.6 If $A=U^a$ and $B=U^b$, then $A\times B=U^{a+b}$. This algebraical identity links multiplication, $A\times B$, with addition, $a+b$. It was the genius of John Napier of Merchiston that saw that if we had a means to pass easily from A to a and from B to b, we had also a means to pass easily from $(a+b)$ to $A\times B$. That is, if we had such a means, the heavy labour of multiplication could be replaced by the lighter labour of addition. And Napier not only saw this as a theoretical possibility, he also saw how such a means could be set up in a table, did the necessary computations, and published the result at his own expense in 1614: *Mirifici Logarithmorum Canonis Descriptio*.

1.7 This was a table which we would today refer to as logarithms to base e. Henry Briggs, of Gresham College of London, saw that logarithms to base 10 would have practical advantages, and Briggs, with encouragement from Napier, computed these, and in 1624 *Arithmetica Logarithmica* was published. Briggs's work was carried further by Adrian Vlacq, a Dutchman, who published in 1628 the second edition of *Arithmetica Logarithmica*, containing logarithms (to base 10) of all the integers from 1 to 100,000, to 10 decimal places.

1.8 Finally Briggs computed the logarithms of the trigonometrical functions, and these were published by Vlacq, at his own expense after Briggs's death, as *Trigonometria Brittanica*.

1.9 It is an encouraging story of friendly co-operation, but it is also the start of great developments in astronomy, surveying, and probability theory, all made possible by the great increase in computing power which came with logarithms.

1.10 These developments were also aided by improvements, made during the subsequent 300 years, in the printing and layout of tables, in methods of interpolation, and in providing tables of differing sizes, from four-figure logarithms to 20-figure logarithms.

1.11 Of particular interest to actuaries is the production, towards the end of the eighteenth century, of addition and subtraction logarithms. (These enable us, given log a and log b, to find log $(a+b)$ with only one table entry instead of the three table entries which would be needed if we had only ordinary logarithms.) (See King, G. (1887), chapter XXI and Spurgeon, E.F. (1922), chapter XX.)

Slide Rules

1.12 Suppose that on a straight line we mark off a units of length from point 0 to point A and then mark off a further b units of length from point A to point B. Then the length from point 0 to point B will be $(a+b)$ units. Modern Cuisenaire rods for children make use, of course, of this fact.

1.13 This geometrical principle was combined, in 1620, with the work of Napier on logarithms, by Edmund Gunter. He constructed a scale in which the distance from the mark '*1*' to the mark 'x' was proportional to $\log x$. To calculate $a \times b$, the lengths corresponding to $\log a$ and $\log b$ (i.e. from mark '1' to mark 'a' and from mark '1' to mark 'b') were each laid off by dividers on the scale and carried to another line. The sum of the two lengths, which is $\log a + \log b$, that is $\log (a \times b)$, was carried back to the scale, where $(a \times b)$ could then be read off.

1.14 William Oughtred carried Gunter's invention a stage further by using two Gunter's scales which could slide one against the other. This got rid of the need to use dividers, and gave us the first logarithmic slide rule, in 1621.

1.15 This was the starting point of three centuries of development by instrument makers, aiming at greater accuracy and at greater ease of handling. Slide rules were still used by actuaries until quite recently.

Napier's Rods

1.16 Napier published his work on logarithms in 1614. In 1617 he published another work *Rabdologiae libri duo* which deals with methods of abbreviating arithmetical calculations. It is in this work that he describes his 'rods', a device for multiplication. In ordinary long multiplication with pencil and paper we form the partial products $a \times b$ mentally, and write them down with due regard to place. With Napier's rods the products $a \times b$ are recorded on strips of ivory, and can be placed together in such a way that the products that have to be added together are placed together.

1.17 Although convenient for multiplication, it would have been impossible to use Napier's rods for division without employing a table of reciprocals, and this might be one reason why the rods did not supersede logarithms.

Calculating Machines

1.18 If we take a 'calculating machine' to be a device in which numbers are represented by sets of discrete objects and in which arithmetical operations are carried out by acting on these sets of objects, then the Chinese abacus is the first machine to consider. It has a set of wires in a frame, the wires corresponding to units, tens, hundreds, and so on; and on each wire there are five beads above the bar and two below it, which between them can be used to represent any digit from 0 to 9. The operator moves the beads on the wires, and the operator has to deal with the carry-over from units to tens when using the machine for addition. Multiplication is dealt with by repeated addition. The machine can also be used for division, though the method is complicated.

1.19 The abacus has been in use for thousands of years, beginning in India and spreading to China and to Europe. For reasons which are not clear, its use in

Western Europe declined in the fifteenth century, but in Eastern Europe and the Far East it is still in everyday use in shops.

1.20 In the seventeenth century we come to a great development: the representation of digits by teeth on wheels. Toothed wheels made to a high degree of precision had become available through the developments in clockmaking, and in the seventeenth century we get the application of this to calculating machines.

1.21 The inventors of the machines not only saw that the teeth of a wheel could represent a digit, they also saw that a train of wheels could be used to deal with units, tens, hundreds, etc. *and* they saw that tens transmission, which in the abacus is dealt with by the human operator, could be dealt with automatically by the wheels themselves. A single pin projecting from a wheel with ten teeth could, once every revolution, move the wheel on its left forward one position.

1.22 All this was the work of many men. For example, Wilhelm Schickard described a calculating machine in 1623 in a letter to J. Kepler. The only example was made of wood and subsequently destroyed by fire.

1.23 In 1642 Pascal completed the first known metal calculating machine, an adding and subtracting machine in which the human operator merely put in to the machine the numbers to be added or subtracted. In the Pascal machine there was only one register. It had six dials, representing units, tens, hundreds, etc. These were rotated by means of a stylus, rather like operating a telephone dial today. Each dial had a carry-over mechanism on reaching 10, so that the machine operated like a modern gas meter.

1.24 In 1673 Samuel Moreland invented a 'multiplying machine', which was an improvement on Napier's rods, in that the products could be brought mechanically into the correct positions. However, these products had still to be summed mentally and therefore the machine did not carry out the full operation of multiplication by mechanical means.

1.25 This problem was overcome by Leibniz, who in 1694 completed the machine he had first thought of in 1671. This machine carried out the full operation of multiplication by a mechanical process.

1.26 In the Leibniz machine we have two registers, the register for the number that is to be added, and the register for the total. These registers are joined to two sets of wheels, the wheels of the number that is to be added, and the wheels for the total. In the wheels for the total each wheel has ten teeth, but in the wheels for the number that is to be added we have a brilliant invention, the Leibniz stepped reckoner, which enables the operator to set for each wheel separately the number of teeth that will engage with the corresponding wheel for the total. Once a number has been set in the machine in this way it remains in the machine until the operator removes it. So, with the Leibniz machine we have the possibility of *repeated* addition, and so of *multiplication*.

1.27 Moreover, with the Leibniz machine, we can move the wheels which represent the number that is to be added relative to the wheels which represent the total. For example, if we have to multiply by 23 we replace 23 turns of the handle by 3 turns, 1 shift, 2 turns. This appears to be very similar in principle to the basis of twentieth century mechanized calculating machines. The reason the Leibniz machine did not go into commercial production at the time was that its performance was not perfect, because the best workmanship of the time did not reach a sufficiently high standard.

1700–1820

1.28 By 1700 machines that could be used by a human operator for addition and subtraction, for multiplication by repeated addition, and for division by repeated subtraction, had been made and had worked. However, each of the machines that had been made was a costly piece of individual craftsmanship, and there was no widespread use of them either in business or in science. They were exciting possibilities, not working tools.

1.29 The development of the next 100 years was a continuing process of making the machines more reliable and less expensive, and was a part of all that we put under the broad heading of the Industrial Revolution. It was the work of mathematicians and of highly skilled craftsmen from the world of clock-making and weaving machinery. No attempt will be made here to summarize it, other than to list (with dates) those who are mentioned in the Science Museum's *Catalogue*:

1724	Leupold
1725	Lepine
1730	Boiste-sandeau
1735	Gersten
1750	Pereire
1774	Hahn
1775, 1777, 1780	Stanhope and Bullock
1783	Müller

1.30 However, it was not until 1820 that we get a machine which could be manufactured on a commercial scale, the arithmometer of Charles Xavier Thomas, of Colmar in Alsace. It embodied the results of 200 years of invention and experiment, and its basic design was the foundation for most subsequent mechanical desk calculating machines. It had three registers:

(a) a setting register into which a number could be set by moving levers;
(b) an accumulator register, into which the number on the setting register could be added or subtracted by turning a handle;
(c) a counting register, for counting the number of times that the number in the setting register was added to the accumulator.

The mechanical means by which digits which had been 'set' into the machine could be added to the number in the accumulator register was based on the Leibniz *stepped reckoner*, which was first used in 1694, in Leibniz's machine.

1820–1914

1.31 The developments in this period are along two lines:

(a) Developments of machines which are 'descendants' of the Thomas arithmometer, i.e. three-register machines, in which a number A was set in one register, a handle was turned B times, recorded in a second register, and the number $A \times B$ was added to a third register.

The aim was to make them lighter, less noisy, easier to operate, and cheaper. Reliability, too, was very important; and we find writers who recommend that calculations made on one machine should be checked on another machine, preferably of another make. Cost was, of course, an important factor, and by the end of the period the real cost of a calculator had fallen substantially.

(b) The creation and development of the key-driven adding machine. This machine with one register into which numbers can be added by pressing keys manually, may be regarded as beginning in 1887, when D. E. Felt patented his 'Comptometer'. These machines and other makes (for example, the Burroughs) became the most widely used *business* calculators. One could 'touch type' very fast and some actuaries became quite proficient. Like machines of the arithmometer type they have a similar history of improvement.

1.32 Another interesting feature of comptometers is the manner in which the ways of using them was extended. Mechanically the machine can do nothing but add; but it can deal with subtraction by addition of complements. For example, to find $42-27$, we add $42+(99-27+1)$, i.e. we add $42+73$. This gives 115. We disregard the leading 1, and we have 15, which is $42-27$. The transition from 27 to $(99-27+1)$ was done mentally by the rule: take each digit from 9 and add 1 to the units digit.

1914–1964

1.33 At the beginning of this period the Napier Exhibition presented a survey of 300 years of development of machines which used the toothed wheel as the fundamental device. By the end of the period we have machines in which the electronic transistor is the fundamental device.

1.34 During this period there were no major developments of 'toothed wheel' machines, but much work was done to make them lighter and easier to handle. In particular, the task of turning the handle was passed to an electric motor, and the task of counting the turns mentally was replaced by the task of pressing a key. This mechanization of some of the control work was carried further in machines (for example, the Marchant) which had automatic division. That is, the operator set the dividend and divisor into the machine and pressed the 'Divide' button, and the machine then carried out a division by the method of repeated subtraction.

1.35 In 1956 the prototype of the first electronic desk calculator was made: this was the Anita. The production model started to appear in actuarial offices in the early 1960s.

1964 and After

1.36 Since 1964 more powerful electronic desk calculators have been developed, with increased storage capacity and a wider range of calculation functions, e.g. automatic square roots. The boundary between 'desk machine' and 'computer' is becoming increasingly blurred. Desk terminals enable staff to gain immediate access to very powerful computers, and give them the ability to write and test their own programs.

1.37 Miniaturization has led to the introduction of pocket electronic calculators which can do all the calculating work of a heavy arithmometer and much more besides. The first one was the Sinclair Executive calculator, which appeared in the early 1970s. Pocket calculators introduced later in the 1970s, and still available today, are often programmable, i.e. the machine will carry out a pre-programmed set of instructions automatically in the right sequence. Some of these instructions can be conditional, with 'branching' and recycling, and hence complex calculations can be carried out in much the same way as on a computer.

1.38 The latest development, and probably a very significant one, has been the introduction of lap-top computers which are easily portable and can be used while travelling. One widely-available, cheap and very practical machine weighs only 2 pounds and is no bigger than an ordinary office file, so that it slips easily into a briefcase. Nevertheless, it has a comprehensive word-processing, spreadsheet and computing capability, as well as the ability to communicate with much larger computers via a telephone modem and with printers via an ordinary cable.

1.39 The potential of this new equipment is considerable and further developments can be expected in the near future. We shall need to search for the best ways to use the new machines and this may well require the adoption of changed working methods.

2. PUNCHED CARDS AND COMPUTERS

Introduction

2.1 In this section we outline some of the key events in the historical development of punched card systems and large-scale computing devices. Our treatment of the subject is by no means fully comprehensive but we hope that it will serve as an adequate reminder of the main points.

Control of Looms

2.2 The earliest use of punched cards is often said to have been in the Jacquard loom. In fact Jacquard (in 1801) was only one of many inventors to use such methods for the control of weaving machinery. Loops of perforated paper tape had been used for this purpose by Bouchon as early as 1725. The object was to vary the operation of the machine repetitively, producing cloth of a given pattern, and to allow the operator to change the pattern readily.

Difference Engines

2.3 At Frankfurt in 1786 E. Klipstein published a book which proposed the construction of an ambitious calculating machine, invented by Captain J. H. Müller, which was to be a difference engine operating from a constant third difference and designed to print out its results on a piece of paper. It was anticipated that the device would be capable of one addition per second and that a table of the cubes of the integers from 1 to 100,000 could be produced in about 10.5 days.

2.4 In 1812 Charles Babbage also conceived the idea of a difference machine, and in 1822 he produced his first model of the machine. As with Müller's machine, the idea was to work on constant n'th differences and build up the function being tabulated by repeated addition. The whole engine, when completed, was intended to have had 20 places of figures and 6 orders of differences. The construction of the machine itself commenced in 1823 and continued until 1833, when work ceased; eventually the project was abandoned.

Babbage's Analytical Engine

2.5 After 1833 Babbage concentrated on the design and construction of an 'analytical engine' of far greater capability than the difference engine. It was intended to calculate and print the numerical values of any given algebraic formula, where a numerical solution is possible, from given values of the variables. The formula was to be communicated to the engine by sets of punched cards, which would also control the action of the machine. The mechanism also consisted of a 'mill' and a 'store'. The operations of addition, subtraction, multiplication and division were performed in the 'mill', and the results were then transferred to the 'store'. The store would consist of a large number of vertical columns of wheels, each wheel being figured from 0 to 9. This highly complex machine was still unfinished when Babbage died, and its construction was never completed. Nevertheless, it represents a landmark in the history of calculating devices, being an attempt to achieve by mechanical means much of what we can do today with electronic computers.

The Scheutz Difference Engine

2.6 In 1834 Georg Scheutz of Stockholm read the description of Babbage's difference engine, and commenced to design and construct models of a machine for the same purpose. By 1840 a model had been made which calculated series with terms of five figures and one difference, also of five figures; in 1842 the model was extended so as to calculate similar series with two or three orders of differences. A full scale machine was constructed by 1853, and a second machine (No. 2) in 1859. A specimen of the results produced was included in the *Philosophical Transactions* of the Royal Society in 1859—this was an extract from a table of logarithms.

2.7 The Scheutz Difference Engine No. 2 can be seen today in the Science Museum, and a good description of its method of working is given in the official catalogue. It consists of two distinct parts, one for calculating and one for printing. Calculations are carried out up to 15 places of figures and the machine registers up to 4 orders of differences. It is the crowning achievement of the nineteenth century in the field of calculating devices, a useful working machine which actually processed large-scale calculations and printed the results automatically, in a good quality typeface. The main use which was made of it was to produce English Life Table No. 3 in the 1860s.

2.8 Punched cards do not seem to have been employed in practical calculation work until the late nineteenth century. All the machines produced before then were controlled by a human operator. Scheutz's Difference Engine might in theory have run by itself for a while, then been stopped and reset from some sort of punched card input, but in fact it was not; on the contrary, it was said to require constant attention to keep it running correctly.

Punched Cards

2.9 The first use of punched cards for data-processing was for the United States of America census of 1890. Data were punched into cards devised by Dr Hollerith, which could then be sorted mechanically. Apart from sorting, probably the only calculation performed mechanically was to count the numbers of cards in different classes, after sorting.

2.10 Punched card machines improved steadily throughout the early part of this century, with great advances both in the ease of punching the cards and in the performance of sorters and tabulators. The impetus for improvement generally came from America, and the latest machines available in this country were nearly always American imports.

2.11 Hooper (1950) describes in detail the combinations of keys that a punch operator has to press in order to represent the letters A to Z. Such machines were still being used in the 1960s, but in fact electric punches with typewriter-like keyboards had been readily available in the 1930s.

2.12 The potential of punched-card machinery for actuarial work was greatly increased by the multiplying punch. This could perform various combinations of add, subtract and multiply operations on numbers punched in one card, and punch the result elsewhere in the same card, taking up to about five seconds. These machines were widely available by the mid-1930s.

2.13 It is tempting to suggest that the quality of the printing must have been a negative factor, tending to inhibit the widespread use of punched-card machinery. The printing was certainly very poor, compared with contemporary typewriters. The tabulators of that time printed only in capitals, and the makers even economized by making the same printed character serve for both 'G' and '6', in addition to the obvious letter 'I' and figure '1', letter 'O' and figure '0'.

Modern Difference Machines

2.14 L. J. Comrie, in his comments on Phillips's paper of 1936 (*J.I.A.* **67**) pointed out that difference engines, as envisaged by Babbage, were on sale not far from Staple Inn, in the form of NCR accounting machines. These machines had six registers, each of which could be added into another; they could therefore be set to print successive values of a function with a constant sixth difference. These machines were used for many years, notably by Comrie, in printing tables for navigational and other purposes. The actuarial profession might well have put them to tasks like the printing of commutation functions. Some actuaries were using them in the 1960s to produce Pension Fund commutation functions, but in the main the profession ignored Comrie's lead.

Electronic Computers

2.15 In the late 1940s, the first electronic computers were being built in various laboratories around the world. In February 1946 ENIAC (Electron Numerical Integrator and Computer), which weighed 30 tons, was dedicated at the University of Pennsylvania. In this country much of the pioneering work was at Manchester University, in co-operation with Ferranti. The Ferranti Mark 1 computer was installed at Manchester in February 1951 and was the first computer to be available commercially on the open market. In the same year UNIVAC (Universal Automatic Computer) appeared in the U.S.A., and LEO (Lyons Electronic Office) in London. By 1953 LEO was doing regular weekly payroll runs for J. Lyons; Lyons also ran the first computer bureau.

2.16 About the same time the National Physical Laboratory was developing the Pilot Model ACE (Automatic Computing Engine). An amusing article by Tom Vickers in Computer Bulletin (June 1986) recalls how this machine was used in the early 1950s to produce the ready reckoners then used for PAYE calculations. The machine was booked to do this job on the evening of Budget Day, normally completing the job well before midnight, though the parameters (tax rates, allowances, etc.) were not revealed until the end of the Chancellor's speech. One year the machine was booked as usual for this task, but the parameters turned out to be unchanged, so the staff all went home. Of course if the Inland Revenue had not booked the machine, that would have given the game away!

2.17 Also in the early 1950s, Powers Samas introduced the PCC (Programme Controlled Computer). This was an advanced punched-card machine, a sort of improved multiplying punch, doing its calculations electronically. The PCC was not a stored-program computer. Its instructions had to be set up by means of connection boards, a tedious and very limited process. Nevertheless, it was quite widely used, perhaps because it appeared as a less radical step forward from punched-card machinery than more advanced machines like LEO.

2.18 However, the large-scale use of computers in business had to await several technical advances, all of which occurred in the late 1950s.

2.19 First, the replacement of valves by transistors led to a great reduction in the size of computers, and also an enormous improvement in their reliability. Second, the introduction, about the same time, of ferrite core storage represented an enormous advance on the best methods available before. Thirdly, printed output began to improve in both speed and (to some extent) quality, with the introduction of line-printers, printing one line at a time (instead of one character at a time) at speeds of several hundred lines per minute.

2.20 These three advantages came together in the IBM 1401, which sold in thousands, far more than any earlier computer. It was originally meant as a sophisticated punched-card machine, with 1,400 characters of storage (hence the name) which were available for both program instructions and data. This may seem very little today, but the 1401 could easily replace and surpass most of the then existing punched-card systems.

2.21 It was not long before the 1,400 storage positions were increased up to a maximum of 16,000, and in the early 1960s the new electronic mass-storage medium of magnetic tape was added.

2.22 This was the route by which most Insurance Offices passed from punched cards to computers. It also represented the point at which many Offices, having made little or even no use of punched cards, took the plunge and embraced the accelerating modern technology.

2.23 In the late 1950s, Manchester University was again in the forefront of technological advance, doing the research which culminated in the Ferranti Atlas, probably the most powerful computer in the world when it was constructed in 1962. It operated at about one million instructions per second (nearly as fast as a modern PC!). Because its main memory was so expensive, the Atlas team hit on the idea of making a slow but large-capacity store (then a magnetic drum) appear to act as fast core store. 'Pages' of data were held either in core store or on the drum; if a program tried to access a page which was currently on the drum, the operating system brought it into core store, swapping it for a page which was not currently in demand. This, of course, is only of value if there is a second program which can usefully be run while the central processor waits for the drum transfers to take place. So Atlas was the pioneer of both Virtual Storage and Multi-programming.

Programming Languages

2.24 In the late 1950s, another great advance began, in the development of programming languages, which allowed the programmer to write instructions like '$A=B+C$', which is considerably easier to write (and less liable to error) than the equivalent instructions in machine code. The computer itself then had the preliminary job of translating these instructions into machine code; but that, of course, was exactly the sort of tedious and repetitive job that computers were particularly good at. COBOL, FORTRAN and ALGOL all appeared about this time.

2.25 The actuarial profession has several times made moves towards specifically actuarial languages, but the cost of producing one has hitherto seemed quite prohibitive. There are at least three problems to be overcome, i.e.:

(a) the representation of complex actuarial functions, with all their super-

scripts and subscripts, in a universally acceptable way suitable for the keyboard;
(b) the difficulty of entering comparatively simple actuarial functions into a generalized format without having to specify zero for each of the non-utilized parameters;
(c) the need for some universally accepted method of calculation where fractional ages and terms are involved.

In fact the mathematically-orientated languages, FORTRAN and ALGOL, both allowed the user to define his own functions, so it was possible in principle to define actuarial operations and functions in an existing language. No such system ever seems to have gained wide acceptance. One reason for this, no doubt, is that the functions would need so many parameters. To define, say, an annuity value completely, one needs to specify mode of payment, age(s), mortality table(s), guaranteed period, interest rate, etc. In any given application, many of these could be taken for granted and would not need to be specified, but a completely general routine would require them all and would be very unwieldy. Another practical consideration would be the treatment of fractional ages. Most mortality tables are defined only at integral ages, and many (probably most) applications use integral ages only. But some applications need fractional ages; and then further problems arise. For instance, does one use linear interpolation for speed and simplicity, or a more complicated interpolation process for greater accuracy? Many users must have developed standard routines to suit their own most common requirements.

Developments since 1970

2.26 In the 1970s and 1980s there have been many new developments. For example, integrated circuits in place of individual transistors resulted in increased speed, and enormous reductions in the size and cost of computers. Independent mini and micro computers were introduced, e.g. the Commodore PET, and these brought computing onto the desk top. Visual display units assisted this change. Inter-active working became visual and much faster, and hence much more user-friendly.

2.27 At the same time a great deal of effort has gone into the production of software for everyday tasks, including wordprocessing and spreadsheets, which have made a considerable difference in practice. This has only been practicable because of the vastly increasing speed and power of computers. Users now typically spend a much higher proportion of their computing bill on software, as opposed to hardware, than was the case in the 1960s.

Pace of Change since 1950

2.28 The annexed diagrams (Figures 1, 2 and 3) give a broad idea of the magnitude of the almost incredible increases in the power and speed of electronic computers since 1950. At the same time user-friendliness has improved

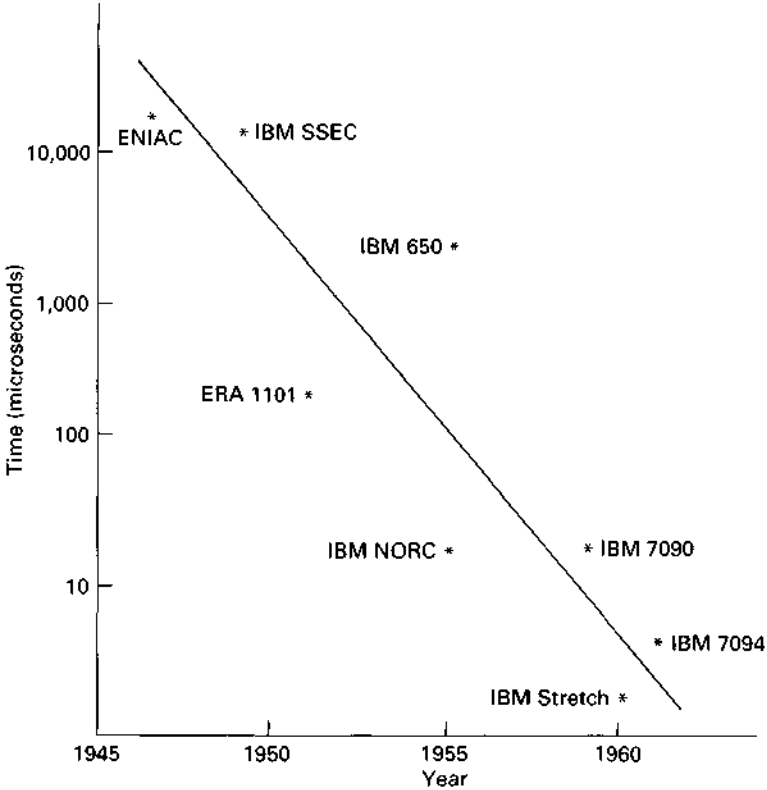


Figure 1. Reduction in multiplication time (approximate values).
Source: R. Moreau. *The Computer comes of age*, 1984.

considerably and hence computers are now no longer the province of the specialist alone.

3. USE BY ACTUARIES

Introduction

3.1 This section considers the use which actuaries have made of the calculating machines which were available to them. Much of the material is based on information gained through a series of interviews with actuaries working, using the machines, at various times in the period since about 1930. Our survey is, of necessity, incomplete and there are many gaps. Nevertheless, the authors are deeply grateful to those actuaries who so willingly took part in the interview

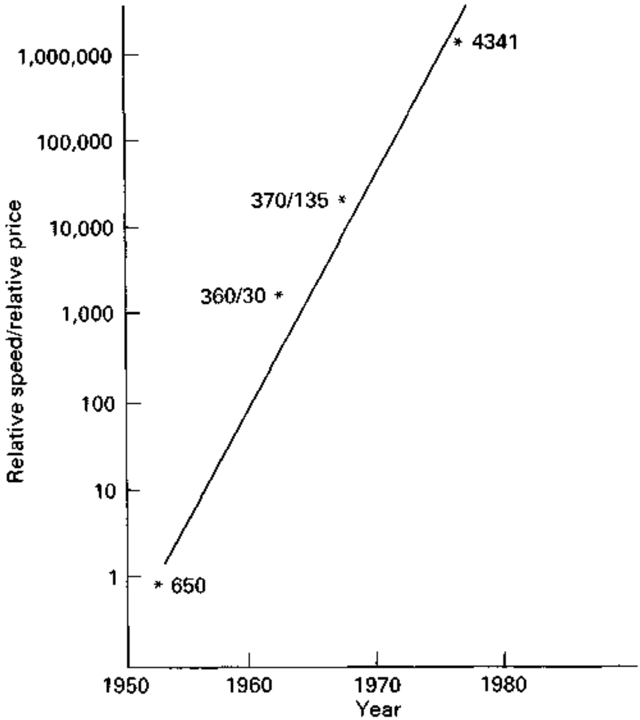
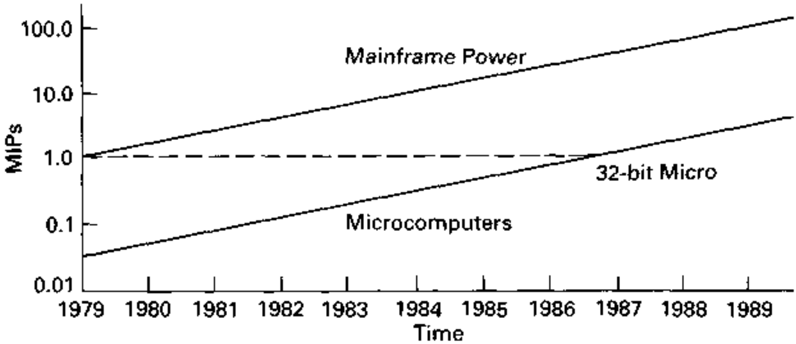


Figure 2. Improvement in the performance/price ratio when speed is taken into account (expressed as relative speed divided by relative price) for some IBM machines. The figure's entries are based on the following data:

IBM machine	Relative speed	Relative price[a]	Relative speed/ relative price
650 (1953)	1	1	1
360/30 (1964)	43	·025	1,700
370/135 (1971)	214	·011	19,000
4341 (1979)	1,143	·001	1,143,000

[a] The cost to execute one instruction per second.
The numbers on the figure's vertical axis are evenly spaced powers of 10.

Source: R. Moreau. *The Computer comes of age*, 1984.



MIP = A million instructions per second.

Figure 3. Computer power in MIPs (1979–1990).
Source: *Electronics—an industry in transition*, Financial Times Business Information, 1986.

programme and offered much assistance with the project. A certain amount of material on earlier usage of machines has been obtained from published sources, notably *J.I.A.* and published actuarial tables.

The pre-1930 use of Machines and Devices to Assist Calculation

3.2 The first known use of a machine for work which could be described as actuarial in nature, although not carried out by actuaries, was the use of the Scheutz Difference Engine No. 2 in the construction of English Life Table No. 3, published in 1864. The engine consisted of two parts, one for calculation and one for printing. Although it saved much labour in the computation and printing process, it was not a simple machine to use. It was vast, weighing about 10 cwt, and, to quote from the Appendix to E.L.T. 3, "the machine required incessant attention. The differences had to be inserted at the proper terms of the various series, checking was required, and when the mechanism got out of order it had to be set right." The printing mechanism automatically produced papier maché moulds which were used to make metal moulds which, in turn, were used in the actual printing process. The tables are a fine tribute to the makers of the machine and to those involved in using it. It obviously inspired those concerned; to quote again: "the soul of the machine is exhibited in a series of tables which are submitted to the criticism of consummate judges of this kind of work in England and in the world".

3.3 A letter in *J.I.A.* **12** of 1865 indicates that Major-General Hannyngton was experimenting with the use of the arithmometer of Thomas de Colmar in actuarial work. A small table, calculated using the machine, is shown and he states, "I am convinced that the days of hand work in the actuary's craft are coming to an end." He followed this up by a paper to the Institute in 1873 (*J.I.A.* **16**) fully describing the use of the arithmometer for calculating actuarial functions. The arithmometer was used in the construction of R. P. Hardy's *Valuation Tables* (based on the H^M table) also published in 1873. Hardy had been familiar with the machine for some time and saw the production of the tables as a good test of its suitability for large scale calculation. He writes: "the results have confirmed entirely the opinion that I originally formed, that the Arithmometer is an invaluable aid, in point of accuracy and economy of time . . . however . . . I do not consider that the instrument can safely be used in wholly unskilled hands, nor by persons who are not familiar with the particular function they are tabulating". The latter sentiments are equally apposite today. George King describes an arithmometer in his textbook of 1887 and a picture of a TIM machine is included in Spurgeon's textbook of 1922.

3.4 It is interesting to compare the conduct of the 1863–93 Investigation undertaken by the Joint Mortality Committee of the Institute and Faculty of Actuaries and the 1870–1900 Investigation undertaken by the Actuarial Society of America. In the United Kingdom investigation computation started in 1896 and was completed in 1899. There were close on one million data cards (the numbers received were estimated by weight) and at the height of the activity there were about 35 persons involved in the work. Many thousands of hours of labour are faithfully logged. While the sorting was manually done, at least some of the subsequent calculations were done by machine: to quote from the Official Supervisor's Report No. 10 "For the purposes of this investigation . . . a great deal of work has been performed on the Arithmometer; and it was found desirable to arrange (subject to the approval of the Committee) for the purchase of a machine of English make which should be constantly available for the use of the staff. I have to thank also the management of the Prudential Assurance Company for their great kindness in lending me, from time to time, a large number of machines to enable me to complete the heavy calculations involved."

3.5 In the American experience, a report of which appears in *J.I.A.* **37** (1902), punched card equipment was used to sort and tabulate the data. Preparation of data by the companies started in 1901 and it was expected that this would produce about three million policies. It was estimated that a clerk of average ability, in a working day of 6·5 hours, could punch between four and five thousand cards. They had only one sorting machine, but "so rapidly does the machine do its work, that the three million cards will be sorted within four months". It was fully expected that the committee set up to run the investigation would be able to report the final results to the Annual Meeting of the Society in May 1903, just two years from the date that data preparation by the companies started.

3.6 By the time the 1900–20 investigation was being run (which resulted in the publication of the *a(m)* and *a(f)* tables in 1924) the approach in the U.K. was very different from that adopted 20 years earlier. All data tabulation was done from cards, prepared by the contributing offices, which were processed by the Accounting and Tabulating Corporation of Great Britain using Powers machines.

3.7 The problems of computing actuarial functions, particularly the more complex functions, have exercised the attention of actuaries from the earliest days of the profession, and various devices to ease the labour are described in the pages of *J.I.A.* For example, a paper in *J.I.A.* **2** (1852) describes a method of constructing survivorship probabilities and present values of survivorship assurances by means of logarithms of the basic functions (l_x, d_x, etc.) which are recorded on strips of paper, a separate strip being produced for each set of single life functions. The required strips are then set side by side so that functions for the required combination of ages can be read off in a straight line across the page. Reference is made in this paper to Sang's Life Tables of 1841 which were constructed using a similar method. A paper in *J.I.A.* **14** (1868) by Jardine Henry describes a triangular instrument which utilizes the geometry of similar triangles to calculate the D numbers (l_x, l_y, v^x) required for tables of joint life annuities. The instrument was extremely quick and simple to use and had been utilized by Henry in the production of the Government Annuity Tables published in 1859.

3.8. There were occasional references to tables of quarter squares for use in multiplication, making use of the equality $(a+b)^2/4-(a-b)^2/4=ab$. A letter in *J.I.A.* **9** (1860) shows a method of calculating policy values using such a table, but the use of the method generally appears to have been minimal. This is perhaps surprising if one remembers that ready reckoners such as Crelle's Tables were a popular alternative to logarithms, and that a double entry table of 1000*1000 would be many times the size of a volume containing the quarter squares for the same range of calculations.

3.9. Amid all this it is interesting to note the contribution of Lt. Col. Wm. Henry Oakes, who put forward 'A Method of Multiplication which may be practised mentally' (*J.I.A.* **10,** 1863). It is certainly neat and, with practice, could well be quicker and less error prone than the conventional long multiplication. Over a century later it is easy to be dismissive of such contributions. However, at that time the burden of computation must have loomed large in the mind of the practising actuary. Any technique which offered some relief would at least be worthy of serious consideration.

3.10 Some of the earlier actuaries had to carry out enormous volumes of manual calculation. For example, the Institute Library possesses eight volumes of neatly handwritten tables laboriously calculated by John Finlaison, the first Government Actuary in the nineteenth century. George King did various extensive calculations by hand in order to establish the effect of different valuation bases for the purpose of several Institute papers written around 1900—work which could have been accomplished by a modern computer within a matter of minutes. F. M. Redington presented a paper on patterns of mortality in February 1969, when he indicated that much of the work had been done very laboriously by hand and commented:

"Future exploration will undoubtedly be computer-based, although I am fearful that the computer may have the same effect on our minds as the car is having on our bodies."

The use of Mechanical, Electrical and Electronic Machines from 1930 onwards

3.11 During the 1930s the calculating aids in use in actuarial departments were logarithms, ready reckoners (e.g. Cotsworth, Crelle's Tables), slide rules and mechanical desk top machines. Although logarithms are included in the list they were apparently not in widespread use by this time and it is probable that they dropped out of use completely at some time during the 1940s. Similarly, the use of ready reckoners was by no means universal. However, those who did use them seemed reluctant to part with them. For some tasks they were felt to be easier to use than hand machines and they certainly had the advantage of being silent in use. In many offices ready reckoners and hand machines were run in parallel, the aid to be used being determined in some cases by the preference of the actuary concerned and in others by the nature of the task in hand. The use of ready reckoners appears to have ceased in the late '40s or early '50s.

3.12 We received several reports of the use of circular slide rules, variously known as Fuller's Rules, carbics, guns or, in one case, a rolling pin. They were very popular among those who used them and were thought to be quicker in use than hand machines. They were accurate to four significant figures and were particularly useful for one-off calculations, e.g. surrender values. There is evidence of isolated continued use until the early 1970s.

3.13 It is difficult to be specific as to which machines were in use in the 1930s. In one large office each staff member in the actuarial department is said to have had an arithmometer, and there was much rivalry among the members to be the fastest user. It is, however, thought that the term arithmometer was being used in a generic rather than in a specific sense. Particular machines recalled as being in use at that time were Spitz, Mercedes, and Monroe.

3.14 The first electrically operated machines began to appear in actuarial departments in the '30s, the names Muldivo and, again, Monroe being mentioned. The Muldivo had the reputation of being a formidable looking machine but being far quicker, and much less onerous, to work with than the hand operated type. It is interesting to note that more than one respondent reported a similar division of labour within the office, namely that calculations for OB business were done in the actuarial department on hand machines while in the IB department much calculation was carried out by pools of (female) clerks using comptometers.

3.15 By the 1940s, and into the 1950s, Brunsvigas (first manufactured in 1892) and hand Facits are recalled as being in widespread use. The Brunsviga has been described as the Rolls Royce of calculating machines. It was obviously much liked and has clearly served its masters well, although it was by no means universally loved.

3.16 Electrically powered machines came into more common use over this time and in the early '60s electronic machines became available, the first of these being the ANITA. While it is recognized that they saved much labour in long and tedious calculation sets, essentially actuarial methods did not change. There appears to have been a wide variety of machines in use, with their distribution

Photographs on p.233-248 omitted for copyright reasons being somewhat haphazard. Certainly the number of different machines available had increased and the choice of the best machine for the job would not necessarily have been an easy one. Some were very complex, with several registers, and were not particularly easy to use: the sequence of calculations had to be worked out very carefully to obtain maximum benefit from the facilities available.

3.17 Machines at that time were relatively expensive. One actuary recalls that, on starting work in 1957, a Monroe electric machine was bought for him at a price of £350, his own starting salary being £279 p.a. Actuaries did not always have control over which machines they should use. In some actuarial departments the actuaries did try out and choose the machines to be purchased, not infrequently being grilled by finance departments to justify the expense. In other offices machines were purchased centrally and allocated to departments on the basis of requirement as perceived by the purchasing department rather than by requirement as perceived by the ultimate user. Office life obviously had its lighter moments. One department referred to its electric calculator as the 'tango' machine: on being set to divide by 131313 . . . it beat out a tango rhythm. Another had a machine where the digits appeared like dancing girls as they came up on the register. One ponders the effect were both machines to be used together in the same office.

3.18 With the increasing use of computers since their introduction in the late 1950s, conventional calculating machines have fallen into disuse. (One of the offices we surveyed was, however, still purchasing new hand Brunsviga-type calculators in the late 1960s!) The actuary of today is most unlikely to be using a machine of the type we have been considering. At most he will, perhaps, have a pocket calculator for individual, one-off calculations. If he uses a machine, it will probably be a stand alone PC or a terminal attached to a mainframe or mini computer. Increasingly he may also have a small laptop computer tucked into his briefcase. Having said that, it is surprising how many actuaries will confess to having an old and trusted machine secreted in a cupboard or a drawer, perhaps used from time to time, from which they refuse to be parted.

Uses of Punched Card Equipment

3.19 The advent of punched card equipment was obviously a major boon to those involved in large scale data handling. It is believed that the first installation by an insurance company in the U.K. was set up in 1918. This system was used to maintain details of policies in force and to sort these into groups as required for different tasks. Each department, OB, IB, general, had its own system operated by teams of women. All district offices had printouts of policies in force in their area and could pay claims promptly without awaiting Head Office authority. The first specifically actuarial use of punched cards appears to have been in connection with bonus distribution, with work on the valuation coming later. While offices were beginning to use punched card equipment in the 1920s, its use does not appear to have caught on particularly quickly. A paper in *T.F.A.* **12**, published in 1929, describes the use of punched card equipment in connection with life (ordinary) business and suggests that its use was not widespread.

3.20 While the information we have obtained on the later use of punched card systems in actuarial work is extremely limited, the indications are that the use of such equipment was not by any means universal. To quote from the section dealing with Great Britain in the *Transactions of the XVth International Congress*, held in 1957 and which had a major emphasis on data processing in insurance, "The larger companies maintain valuation records with the use of punched card machinery and some of them actually employ punched card machinery for calculation of valuation results." Some offices never used punched card machinery at all, passing straight from manual methods to computers. One office in our survey reported just this sequence of events. Punched cards as a data storage medium have been overtaken by magnetic tape and computer disks, while their limited calculation facility has been superseded by computers of varying degrees of sophistication. There is evidence that punched card machines were still in use in some offices in the 1970s but it is unlikely that much, if any, use is made of such equipment today.

The use of Computers

3.21 Unlike the experience with punched card equipment, where actuaries in Britain were slow to get involved with its use, actuaries have been involved with computers from the earliest days of such machines becoming available. ICT launched their PCC (Programme Controlled Computer) in 1956. In our very limited sample two offices acquired one in 1957, in a third its use was reported as well-established by 1959. A fourth office reported using a bureau machine for bonus calculations before later acquiring their own machine. The stories told by actuaries involved with the early machines make fascinating reading. Machines arrived with minimal instructions as to their usage. ICT ran programming courses of one week's duration, with no printed manual to take away. One actuary recalls writing his own manual on returning from one such course. The machines were programmed in machine code, the maximum programme size being 160 instructions. Data storage was minimal. Once set up (by means of rivets punched into sets of programme boards) the programme could not be altered without physically removing the programme boards and resetting them. Work on these machines was mainly in connection with bonus distribution or valuation. The machines were very reliable and proved their worth. One office reported having had doubts when ordering their first PCC as to whether there was really enough suitable work to justify its purchase: within five years they had ordered a second machine and both were kept busy.

3.22 During the 1960s it would appear that the majority of offices were computerizing, the pace varying from office to office. Computers seem to have been regarded, in many cases, as the domain of the actuaries. The most frequently mentioned programming language was FORTRAN. One suspects that there was a considerable gulf between those who were computer literate and those who were not. Machines at that time were not particularly user friendly. Clearly there were actuaries who could see the possibilities and were in the forefront of usage development. Many others, however, probably had computers thrust upon them and had to make the best of the situation.

3.23 During the '60s computers were used for two main tasks running in parallel. Firstly there were the office housekeeping functions—the maintenance of policy records and the assembling of valuation data. Flexowriters were introduced to produce policy documents directly from computer files. It was at this time that, particularly in some of the larger offices, separate data processing departments grew in importance. While actuaries were often involved in setting up the systems, the day-to-day running was done by others. In some quarters this led to a feeling that actuaries had lost control over the valuation data, for the certification of which they carried the ultimate responsibility. On the other side of the coin, the proposition that large scale data handling was definitely not the preserve of the actuary was proffered by more than one source.

3.24 The second main group of tasks were the strictly actuarial ones of valuation and bonus distribution. In the main computers were used merely to automate existing methods. There appears to be a general feeling of regret about this, a sense of missed opportunity. The reasons in almost every case were the lack of both the time and the resources to consider in depth the possibilities raised by the new technology. Full use was made, however, of the speed of calculation offered by the new machines. It was now possible to produce results on different bases, try out a range of parameters and thus have far more information available on which to base decisions. The 'what if?' scenarios could be tested.

3.25 Notwithstanding the above, there is evidence that some actuaries were beginning to explore the possibilities raised by the new technology. Two sessional papers speculating on the potential of digital computers were presented to the Institute in the early 1950s, viz. Michaelson, *J.I.A.* **79** (1953) and Baker, *J.I.A.* **81** (1955). These were followed in the 1960s by a series of papers describing practical applications of computers in life office work. For example, in 1965 a paper by Barnard, *J.I.A.* **91**, described the use of a small computer to value life policies individually, rather than by the traditional grouped methods. Also described was the calculation of exposed-to-risk by summing the contribution of each individual policy to the whole. Several Faculty papers were also published. One of our interviewees reported a computer being used to construct a model office for pension business in about 1970, which was utilized in the determination of policy for that class of business for about twelve years.

3.26 In 1966 a paper by S. Benjamin, *J.I.A.* **92**, looked at the possible effects of computer knowledge on actuarial work. The paper looked at the problem on several different levels, ranging from the effect on management techniques down to detailed algorithms for specific problems. Although in some areas the ideas may have been ahead of their time, the paper put the issues involved before the profession very clearly.

3.27 Throughout most of the 1960s the Students' Society ran a programming course during the winter months. It was a very full course, equivalent to one part of the examinations in extent. About 250 actuaries passed through it, representing a large proportion of the then current generation of younger actuaries. The final program introduced simulation as a practical actuarial technique.

3.28 While we have little direct evidence of specific computing activity in the 1970s, one has the impression that this was a period of consolidation and expansion. The next major step forward was the arrival of PCs in the 1980s. Not only did these machines give actuaries relatively large amounts of computer power at their fingertips, they were also much more user-friendly than their mainframe counterparts. Our evidence suggests that their distribution is widespread among members of the profession and that many and various are the uses made of them. The availability of standard packages such as spreadsheets, wordprocessing and graphics have opened up their use not only to those who are highly computer literate but also to the less electronically minded practitioner.

3.29 Major advances appear to be being made in the integration of separate departments into a more coherent whole and with the linking of branches to Head Office. In this connection PCs are often used both as terminals linking in to access data held on a mainframe and as stand-alone computers manipulating the data so retrieved. However, it should be said that actually moving data from say a mainframe to a micro, is not always the simple task it might appear to the uninitiated.

3.30 Many offices are now developing 'model offices', which simulate the future experience of the office, on specified sets of assumptions regarding investment, mortality, expenses, bonus rates, etc. Some model office programs are fairly simple and are used for such tasks as checking valuation results, analysis of surplus etc. Others are extremely sophisticated and are used as an aid in determining policy, for example assessing the profitability of new types of contract or matching investments to emerging liabilities. Some have the facility to change individual parameters so that, for example, the possible impact on the portfolio of increased mortality due to AIDS can be studied. Not all offices are developing model offices, however; some are content with their existing methods.

3.31 New products which rely on sophisticated computing power for their operation, such as universal life policies where the policyholder has a high degree of choice over the specific areas to be covered by his premium from time to time, are being developed. Such products would have been quite impossible to contemplate previously. Another example is the allocation of units for unit-linked policies on the day the money was received instead of once a month, which increased the complexity of the data and its processing enormously. We found that the study of an office which started to write business in the late 1970s was most interesting. The whole operation had been planned in the knowledge that large amounts of computer power would be available. The degree of automation and of integration of the different departments is impressive. It is by no means a paperless office but nevertheless gives strong indications of the way office life is likely to develop in the future.

The use of Machines in the Production of Standard Mortality Tables

3.32 The standard tables produced from the data collected by the C.M.I. Bureau reflect the changing use of machines by the profession. For the first such table, A 1924–29, published in 1934 'all necessary multiplications were made on machines in duplicate'. Reciprocals were set up so that more than one calculation could be done without too much repetition, e.g. $a = N \times D^{-1}$ and $A = M \times D^{-1}$. Logarithms of certain of the commutation functions were published with the tables, indicating that it was expected that logarithms would still be in general use by offices at that time.

3.33 Nearly 20 years later, in 1953, the *a*(55) tables were published. As with A 1924–29, the bulk of the monetary functions were calculated on machines in duplicate but the preface indicates that the joint life and last survivor functions were produced by computer.

3.34 The A 1949–52 tables published just a few years later, in 1957, utilized much more sophisticated equipment. All the monetary functions were calculated by LEO Computers Limited, using LEO, the data supplied to the computer being i, $l_{[x]}$, $l_{[x]+1}$ and l_x. The results were tabulated by means of an electromatic typewriter owned by the National Physical Laboratory and the tables were reproduced by photolithography.

3.35 The A67/70 tables published in 1975, and the *a*(90) and PA(90) tables, published in 1979, were entirely computer produced, the only input required being a formula to calculate the mortality functions, the mortality reduction factors and the rate of interest. The results were written to magnetic tape, from which they were computer typeset onto film. The film was used to produce the bound volumes. In addition, a computer routine was available to allow offices to produce their own double entry table, with the facility to vary the mortality reduction factors if desired.

3.36 When FA 1975–78 was published in 1983, no monetary functions were published with it. The rationale was that those likely to use the tables would have computer power available to them and they would either be using methods which did not require commutation functions or they could easily produce them if they were required. It is worth paying tribute to the early nineteenth century actuaries who invented commutation functions, a calculating aid in themselves, with their summation columns which allow subtraction to take the place of varying summation ranges, thus saving enormous amounts of calculation. The technique was still found useful in the early days of computers, when calculation power was still comparatively limited. However, it is debatable whether the profession will ever again require the production of volumes of standard monetary functions. Is not the time fast approaching when all that really need be published is the formula to calculate the mortality functions, which offices can insert into their actuarial computer programs as appropriate?

Changes in the Way the Actuary does his Work

3.37 At the time that the first of our interview subjects were starting work, in the 1930s, the new recruit to a life office would join an actuarial department which was very much a self-contained entity. He would very probably start off calculating surrender values, a daily ritual following a very clear set of procedures. After a couple of years, during which he would become thoroughly familiar with the underlying principles, he might well progress to the processing of claims, and so on round the office. The ultimate move would usually be to valuation. Throughout this time he would, of course, be studying for the actuarial exams and by the time he was qualified he would have a thorough practical experience to add to the theory.

3.38 In more than one office in our survey, valuation was a great social event. Extra staff were drafted in from other departments, which could give the young actuarial recruit his first taste of the responsibility of being in charge of others. Much overtime was worked, with refreshment breaks providing a much appreciated period of relaxation from the otherwise hard grind of long and tedious calculation.

3.39 The organization of the departments and the methods used had probably changed very little over the previous 50 to 100 years. Nor were they to change for many years yet. The increasing use of machines had little effect on the methods employed although there were, obviously, refinements from time to time. In particular, a number of elegant valuation techniques were derived which made use of the particular strengths of the specific machines available. However, many actuaries still spent a large part of their time engaged in calculations of one kind or another.

3.40 The situation today is very different. The way the senior actuary carries out his work has probably been less affected by the new office environment than has been the case for his junior colleagues. The range of problems he has to deal with, and their complexity, has undoubtedly changed out of all recognition while, on the other hand, the amount of information he has on which to base decisions will also have increased beyond anything dreamed of fifty years ago. However, his rôle is probably more managerial than technical and is in essence unchanged. He will be applying the same set of principles to a different set of problems and calling on different resources to solve them.

3.41 For the junior actuary the advance of the computer has wrought a more fundamental change. A large slice of technical calculation and number crunching, traditionally carried out by students and junior actuaries, has simply disappeared. With increasing automation, tasks which required the exercise of actuarial expertise for their completion can now be programmed to be carried out by non-technical staff at the press of a button. The valuation itself, once the parameters are set, is largely an automatic process, with the actuary being involved in setting the basis and interpreting the results. All this means that the rationale for a large centralized actuarial department is fast disappearing. Two offices in our survey volunteered the information that they have dispersed their central actuarial departments, the staff concerned being assigned to different divisions within the company. They cannot be alone in this and it may be a trend which is set to continue.

3.42 This raises the question as to what all these newly liberated students and junior actuaries actually do. The question is not intended to be facetious: it does raise the issue of how the student of today acquires his or her skills and what is expected of the student once these skills have been acquired. The demand for actuaries goes on increasing relentlessly. Yet does the profession really know how its most precious resource, its qualified and aspiring members, are actually practising their hard won skills in the commercial world of today? Are companies using their actuaries in the most efficient manner? It is an old joke that actuaries are totally unable to explain to those in the outside world what they do: perhaps this is a good time for them to give some fundamental thought, in their own interests, to their rôle in the financial world of today. Modern computing power has freed actuaries from the load of long and tedious calculation. It gives the opportunity to shed the ivory tower backroom image of the highly trained technician doing calculations of unimaginable complexity totally beyond the understanding of the outside world. The opportunity is now there to take a higher profile and apply the actuarial approach to a fuller range of financial problems, unhampered by the constraints of the computation process. That opportunity should not be allowed to pass by default.

Questions raised by the Past Experiences

3.43 We feel bound to raise the question as to whether actuaries have made the best use of whatever calculating aids were available at the time they were practising. In the earliest days, of course, the only aids to hand would have been logarithms, slide rules and, possibly, Napier's Rods. The sheer industry of some of the early practitioners has to command respect. The use of the Scheutz difference engine to produce E.L.T. 3 in 1864 was visionary, yet the Thomas de Colmar arithmometer, first produced in 1820, was not seriously considered for actuarial calculation until the 1870s. We have not been able to establish when the arithmometer became widely available and, of course, there was the consideration of price, yet it does seem strange that a device of such potential should have been so slow to catch on. We have seen calculation sheets for valuations done at the turn of the century, where logarithms were used for all the calculations. Did the actuaries concerned not realize the potential of machines? Were they not in a position to arrange for machines which would assist their work to be purchased? Or were they quite happy to carry on with the old tried and tested methods in the secure knowledge that the world was not changing very much and there was little point in tampering with a system that served their purposes well?

3.44 A similar point could be made concerning punched card equipment for data handling. Punched cards were first used in America, as has already been stated, in the U.S.A. census of 1890, yet it was not until 1918 that, as far as can be established, the first installation was made in a U.K. insurance company, and the spread of such systems was extremely slow. One possible explanation is given by a speaker at the Faculty in December 1929 (*T.F.A.* **12**, 265); he maintained that the earlier machines did not allow enough information to be punched on to one card to be of any practical use, and that British (or at least Scottish) Offices used the new machinery as soon as it was able to do the job required. It is certainly true that early cards had nowhere near the 80 columns which were later standard; the exact number varied, but in the very earliest American installations it was under ten.

3.45 Perhaps the classic example of the profession not recognizing the potential of one man's vision lies in their response to the now famous paper by Phillips on 'Binary Calculation', presented to the Institute in January 1936 (*J.I.A.* 67). This put forward the idea that arithmetic should be done in binary, as it was so much simpler than decimal arithmetic. The paper describes a mechanical device for carrying out such calculations, using cards punched in such a way that the absence or presence of a hole in a specific location represented a 0 or a 1 as required. He also postulated a light ray machine which would read the pattern of holes and do the calculations far faster than the mechanical machine could manage. Phillips reckoned that the light ray machine could perform 40,000 calculations per hour "providing a printed, punched or photographed record in s.n.2." (i.e. base 2) "of every product and, if required, every cumulative total".

3.46 Phillips also put forward the idea of moving from decimal to binary by means of octal notation which, in his mind, would ease the transition. With hindsight this can perhaps be seen as a mistake, as many of the speakers at the meeting concentrated on the problems the conversion to octal would pose, rather than considering the wider potential of binary. However, more constructively, one speaker said "If Mr Phillips could take a number in familiar form, in s.n.10, convert it to s.n.2, multiply it with astonishing rapidity and convert it into s.n.10, so that it could be handled in the familiar form, he would certainly have achieved something worthwhile." One contributor to the discussion "could not conceive that anybody would require products at the rate of 40,000 or even 4,000 per hour". One can only speculate as to how the history of computer development might have been hastened had those present at that historic meeting caught the vision of Phillips and encouraged him in his ideas. The profession was not alone. Phillips offered the patent of his invention to the British Government as a gift: they turned it down.

3.47 When it comes to working with computers, many actuaries have responded to the challenge with enthusiasm. It is clear that much inventive work has been, and is being, done. Is there a case for some pooling of experience in this field within the profession? With such a wide range of machinery, software and potential applications would it not be worth sharing experience? At the lowest level there must be considerable duplication of effort while at the frontiers, as it were, could not a professional 'think tank' approach pay dividends? A certain amount of work has been done on expert systems but there must be other areas where a joint approach might make sense. The advent of computers has revolutionized not only the actuarial environment: their potential must be fully exploited if the profession is to remain in the forefront of technology in the financial field.

4. FUTURE PROSPECTS

4.1 In this section of the report we look at the possible future outlook over the next 20 to 30 years. It should be appreciated, however, that it is not easy to forecast which developments are most likely to come about. Most forecasts made 20 years ago would probably not have predicted where we are today. Looking ahead over the next 20 years, there will inevitably be additional developments which are not mentioned in this report. Some of these may come about as a result of technological breakthroughs which cannot at present be predicted.

Current Position

4.2 The current position is that, in general, micro computers now have a dominant position in life office actuarial departments. The introduction of powerful software packages, such as spreadsheets, has hastened this development. The micros are used not only for traditional actuarial calculations, such as surrender values, but also for a wide range of administrative tasks, such as writing standard letters, initiating changes on the main policy records, producing revised premium rate tables, making projections for unit-linked policy quotations, and processing statistics of work done by the office. One of the limitations has hitherto been that the main policy records have often been held separately on a main-frame computer, and it has been necessary, when dealing with an existing policy, to print out the main-frame policy record and then key-in the details manually into the micro. This limitation is fast disappearing as automatic data transfer between the main-frame and micros becomes commonplace.

4.3 One of the consequences of the introduction of computers has been that a much higher degree of accuracy has been attained than was possible with the old manual methods. This is particularly true, for example, where a whole sequence of operations has to be undertaken after a single event has triggered the process. The computer, unlike a clerk, does not forget to carry out some of its tasks! On the other hand, it still remains true that considerable effort must be put into ensuring that the data submitted to computer systems is accurate (with built-in validity checks wherever practicable).

4.4 Moreover, great care must be taken when writing new computer programs to ensure that they are entirely correct (under all conceivable circumstances) and fully documented. Many of the people we interviewed emphasized this point. Standardized procedures have often been developed, to which computer programmers must conform. We came across one or two instances where considerable difficulties might have been experienced if the documentation of a program had been less complete. Despite the precautions which are taken, it is still possible on occasion for difficulties to arise when a member of staff leaves before the documentation of a program is finished.

4.5 Our enquiries suggest that the use of computers has often led to lower staff numbers than would otherwise have been required, but it has not in general led to lower administration costs, particularly when the investment in the machines themselves is taken into account, including maintenance and software capital and licensing costs. However, computers have enabled offices to carry out tasks which would not previously have been possible, e.g. the administration of complicated life policies. Changes of all kinds can now be introduced more quickly than before.

4.6 Thus, computers are leading us to an increasingly complex world. Whether this constitutes real progress, however, is perhaps a matter of opinion.

4.7 One potentially awkward problem which some offices will have to face in future is that they may find themselves locked into a complex computer system which cannot easily be adapted to meet changing requirements and new technological developments. In such a case the office may well find that it has to introduce a brand new system, starting almost completely from scratch, which could be an immense task. Although such problems have been experienced in the past, the scale of such a task could be much greater in the medium-term future because of the greater intricacy of the systems involved. Ultimately, however, increasing standardization between computer systems could lead to an easing of this problem.

Better Communications

4.8 During the next few years, important developments are likely to take place in the methods used for communication between different geographical locations. Voice and data communications will become fully integrated, so that spoken messages will be able to accompany data transmissions. It will become much more commonplace to transmit large volumes of data from one part of the country to another, as problems of security, reliability and incompatibility between different systems and equipment are gradually overcome. Many kinds of new services will become available in the market place, which will facilitate such developments. Electronic mail systems are likely to become very common and to offer realistic facilities for communication between, as well as within, organizations. On-line information systems, accessed through telephone modems (or later through data ports), will become increasingly useful and user-friendly, with an ever-widening range of data available not only for regular subscribers but also for casual users. In some years' time it may become much more economic than it is today to transmit full colour-TV pictures, leading to more widespread videophones, video conferencing, central education of salesmen, etc. International communications will also become easier, and this may lead to increasing international competition in the market place for financial services. Managers who are travelling will be able to communicate more easily with their offices, through cordless telephones, truly portable computers, plug-in data sockets in public places, and a wider availability of fax machines for public use. Increasing competition may reduce costs in all these fields.

4.9 Better electronic links within offices are already technically feasible and will become increasingly common. For example, colleagues working within the

Head Office will be able to use a common computerized data base which will give them a number of new facilities. On the purely administrative level, the more widespread keeping of office diaries on the computer will facilitate the arranging of meetings. Documents which need to be discussed in draft form by a number of colleagues will be able to be displayed on each person's screen simultaneously and alterations made on the spot, as the people concerned discuss the document by telephone link-up. Similarly, actuarial calculations will be able to be displayed simultaneously on the screens of several actuaries, who will be able to change parameters at will and see instantaneous results as they discuss the calculations on the telephone. The 'images' of documents received in normal typewritten or manuscript form will be stored in electronic form, so that they can easily be called up onto the screen as required.

4.10 Consideration should be given now to installing electronic links between the Head Office and the branches. Not only will this provide an electronic mail system for correspondence, but it will also enable data to be transferred swiftly. Changes in annuity rates, for example, will be capable of being made without notice, whereas at present it often takes several days while branches are notified (though at least one office has already been making changes in its annuity rates without notice for several years). Another consequence may be that Head Office actuarial departments will dwindle in size, with much of the routine correspondence and quotations being handled by the branches without Head Office involvement.

4.11 Offices will also probably seek to establish electronic links with their brokers, so as to enable a better and quicker service to be provided. Electronic links with reinsurers may also be introduced. This could enable reinsurers to verify information more easily by tapping into the cedant's own files—to what extent will they wish to do so?

4.12 Moreover, there is the possibility of direct data links between the Head Office of the life office and the policyholders themselves, who would use home computers in their sitting rooms. Although current experiments in this field are understood to be getting off to only a slow start, it still seems probable that ultimately most of the better-off homes in the U.K. will have their own computers, linked to their TV screen and telephone. This would enable life offices to offer a facility whereby policyholders could, for example, obtain instant quotations of surrender values, loan values, paid-up values, maturity values and death claim values. Moreover, people wishing to select a new policy could make their own comparisons of the rates on offer, particularly for annuities and non-profit policies. The latter service has already been tried but one attempt failed because of incompatibilities between the various computers involved—this kind of problem is likely to diminish in future. Certain services of this kind nowadays exist for use by insurance brokers, and it is probably only a matter of time until such services are extended to the general public. Might we even see the introduction of 'self-service insurance'?

4.13 We are already seeing experiments in the marketing field, whereby life assurance salesmen, armed with hand-held home computers, visit a client and use the latter's TV screen to display sales information. It is but a short step to program these computers (or their increasingly powerful successors) in more sophisticated ways, for example with a personal financial planning program. Again, it might be possible to use the client's telephone or a cellular telephone in order to provide a link with the office main-frame computer, in which case even more powerful sales aids could be brought into the client's sitting room and almost any question answered on the spot.

4.14 At the same time, of course, the salesmen of other financial institutions will increasingly be using their own computers for similar purposes, so the insurance industry will need to run faster in order to maintain its present relative position.

4.15 It is for consideration whether the life assurance industry will continue to need the present normal 3-tier structure of Head Office, branch and broker, given that improved data links will certainly reduce the need for staff, many of whom are at present engaged in 'post boxing' activities as information is passed up and down the chain. Different Offices will probably choose different solutions, but it seems likely that some degree of rationalization and simplification in the structure will ultimately occur. Several possible ways in which this might be achieved can be envisaged, as follows:

(a) a concentration of much of the administrative work upon the branches, with Head Office being reduced drastically in size, and existing links with brokers maintained; or
(b) a concentration of the administrative work at Head Office, with the administrative staff at the branches being drastically reduced, and the existing links with brokers being maintained; or
(c) a reduction in the role of the broker with much more in the way of direct communication between life offices and their clients.

4.16 The development of 'expert systems' may well lead some Offices towards course (a), as these systems will enable much of the Head Office expertise, for example in underwriting, to become available for application by relatively unskilled branch office staff on a standard basis. Expert systems raise the level of skill at which clerical staff can operate, and thereby free the time of the expert for dealing with the more complex problems. On the other hand, some of the newer Offices are already near course (b), with a limited network of branches and with brokers already having direct data links to the Head Office. The whole question of the concentration or dispersion of administrative work is highly complex and many factors will have a bearing, both technological and otherwise. On the technological side, the quality, cost and reliability of networking systems and communication links are really the crucial factors, and constraints in these areas are likely to diminish substantially over the next twenty years. Giving outsiders access to one's databases could give rise to new kinds of security problems.

Changing Requirements

4.17 There is a real danger that legislative requirements will become ever more complex. In the past the requirements had to be comparatively simple but nowadays there is more of a feeling that, with the aid of computers, everyone will be able to cope with complications. The very complex regulations under the Financial Services Act are a worrying indication of what may lie in store.

4.18 It may well be that the format of the DTI returns for life assurance companies will change in due course. Perhaps the Government Actuary's Department, now becoming increasingly automated, will one day seek the data from each office on magnetic tape (or even on-line?), so that the GAD can run its own 'model office' program to identify risk areas?

4.19 Another 'external' requirement which could become more sophisticated is the C.M.I. returns. Thanks to access to large scale computer power, the Bureau is now in a better position to respond to changes in the needs of offices than was once the case. New investigations can be added simply and the degree of analysis possible has been significantly increased. More sophisticated techniques for the analysis of the data can be introduced. Offices could, perhaps, be offered a graduation of their own data, if it were extensive enough.

4.20 Possibly sickness and mortality investigations could be linked so that the interaction of cause of sickness and cause of death can be studied, with its implications for the life assurance and PHI markets. Mortality has for many years taken a bit of a back seat in terms of research interest within the profession but the advent of AIDS may well stimulate a resurgence in the study of this subject, in which sophisticated computing power will be an invaluable aid.

4.21 Immediate quotations will increasingly be expected by intermediaries and the public for premium rates, option details, surrender values, etc. Immediate investment of premium monies into the fund will be required. Policies will become more flexible and complex.

4.22 The changing nature of financial institutions themselves could also have a profound effect. There seems to be an increasing tendency for financial institutions to offer a wide range of services rather than restricting themselves to one speciality such as insurance. There is underlying logic in this development, since a broadly-based financial institution is likely to be more stable in the face of adverse circumstances than one which is specializing in a particular field. This development could lead to increasingly complicated financial packages being developed, embracing many aspects of a person's financial circumstances, and this development will increasingly be facilitated by the introduction of computers which can cope easily with all the complexities involved. Actuaries may well find that they are starting to work more closely with members of other professions and that new tasks, not found in the traditional fields, are presenting themselves.

4.23 A requirement that is likely to come increasingly to the fore is the need to protect computer systems against fraud. Systems are already so complex that they are beyond the complete understanding of any single person, so there are real dangers, not only of unauthorized manipulation of the system but of this happening in a way which is hard to detect. Moreover, as computer systems come to be linked together to a greater extent, the possibility of unauthorized access from outside one's own organization may increase. The current concern about 'computer viruses' is perhaps only a foretaste of much wider concerns in the future. A system is needed whereby incidents can be reported to some central point (without the fear of damaging publicity that sometimes leads to a 'cover up'), so that the extent of the problem can be continuously monitored.

Effect on Future Actuarial Work

4.24 What effect will all these changes have on the actuarial profession? One problem for actuaries lies in determining whether the results being produced by increasingly complex computer systems are really correct. It is impossible to see what is going on inside the computer and numerical answers obtained tend to be relied upon blindly once a program has passed through its initial testing. There may well be a case for actuaries to develop new ways of checking the results of calculations by inspection, using approximate methods. We were told that one office had found that the only way of checking the results of one particularly complicated program was to write another independent program which would do the same thing!

4.25 There is a temptation to believe that computers are always accurate in their calculations because experience tells us that they usually are. However, computers can produce results which are not wholly accurate and actuaries need to be aware of this. Some examples are set out in a paper by R. F. Churchhouse (1980). Among other things, he demonstrates that if a series of terms is summed by a computer, the result is sometimes significantly different if the summation is repeated in the reverse order! Could this open up opportunities for fraud?

4.26 Possibly an actuarial notation for use with computers will be developed. Progress on this has so far been slow, though it is not clear whether the lack of such a notation has hitherto been a significant handicap to the profession. Increasingly, however, as new standards are gradually introduced throughout the telecommunications and computing industries, to reduce problems of hardware compatibility and the need to learn different methods, the lack of a standard notation within the actuarial profession will be seen as a hindrance. Moreover, in those work areas where standards are laid down externally, actuaries are likely to make better progress if they observe the standards, where possible, rather than seeking to avoid them.

4.27 It seems likely that, as time goes on, the actuaries in many life offices will develop complex 'model office' programs, which will enable the life offices to make business decisions with confidence. In particular they will be able to investigate the effect on their shareholders of following different strategies. This may well lead to a situation where some offices feel less need to retain an excessive 'estate' as a contingency margin. Offices which do retain an excessive 'estate' may find themselves taken over. There is likely to be increasing interest in the affairs of one's competitiors, and a program could even be developed to simulate the position of an office one is thinking of acquiring! Increasing attention is likely to be paid to the DTI returns for one's competitors. Commitment by top management is a vital prerequisite to success in the development of a model office and in the acceptance of its results as a useful background for decision making.

4.28 It is suggested that actuaries will no longer be seeking to run their business on the basis of average expectations, but will be looking much more at the possible range of outcomes round the mean. This extends not only to actuarial calculations—where actuaries are already becoming used to looking at a range of outcomes—but also increasingly to strategic business decisions. In the past 'hunch' would have played an important part in such decisions, and there will still be room for this in the future, but increasingly there will become available a wide range of factual information and projections etc. which will need to be taken properly into account before decisions are made. The timescales for decisions will be reduced—it may become commonplace to change annuity rates several times a month, for example, and bonus declarations and pension fund valuations will become more frequent. The actuary will therefore need to have a deeper understanding than ever before of the limitations of the actuarial and computer techniques, and the extent to which the figures presented to him are meaningful, but he will also need to be much more of an ordinary businessman, taking account of the 'real time' actions of competitors and making quick decisions without pausing too much for reflection. He or she will therefore need not only mathematical skills but the ability to analyse complex business problems and come up with the right courses of action without delay. Do we need to think about changing the entry standards for the profession, so as to eliminate right from the start the kind of person who is going to be a mathematics specialist only?

4.29 One of the reasons why actuaries in future will need to possess a broader range of skills is that they are otherwise in danger of being 'squeezed' by other professions, for example, accountants. We need to ensure that we are not saddled with a 'back room' image and we need to demonstrate that we are the masters of the new computer systems, rather than their servants.

4.30 Moreover, it may well be that the increasing powers of computers will act as a spur to the development of new theories in actuarial science, in much the same way as the seventeenth century saw the development of new theories relating to probability and to the valuation of life annuities, which could not have been applied in practice prior to the invention of logarithms earlier in the century. We are perhaps already beginning to see this happen in the development of ways of optimizing investment portfolios, based on new and complex theoretical considerations. Who knows what other new theories might be developed in future, as our power to put them into practice increases?

Implications for the Training of Actuaries

4.31 All of these changes have important implications for the training of future generations of actuaries. Indeed, some of the practical problems resulting from these changes are already becoming apparent. It is difficult to ensure that actuarial students nowadays can get a proper idea of the functions of a life office. Much of a student's everyday work is often connected with writing computer programs, and it may be difficult for the student to see how a task fits into the overall scheme of things. There will in future be even less in the way of routine calculating work for actuarial students, and there might also in future be less to be done in the field of computer programming than has been the case in the last few years, when offices have been building up their systems.

4.32 In future the training given through the Institute Education Service will need to place at least as much emphasis as at present on the theoretical structure of life offices and pension funds, since most actuarial students will not easily see the underlying rationale in their everyday work. The need to check numerical results by approximate methods must be stressed, and training given in the development of appropriate techniques for this purpose, which can be applied without using a computer. Students should be given practice in the solution of complex 'business problems', where a wealth of information is available and it is a question of 'seeing the wood from the trees'. They should also be trained in model office techniques.

4.33 The Institute Education Service will itself, no doubt, use electronic techniques increasingly. For example, actuarial literature may be held on a database where it can be called down by students.

Keeping abreast of Developments

4.34 One of the difficulties which actuaries face is that of keeping abreast of changing technological developments. This is nothing new: the same complaint was made in a *J.I.A.* Book Review in 1905, when the field of mechanical aids to computation was described as "seemingly wide enough to be bewildering". However, the Book Review concluded: "In the arsenal of tools he is permitted to explore, a good workman is not at a loss to select that best suited to his task." It is more important now than ever before that actuaries make themselves aware of what is available and just round the corner, and that they play a key role in deciding which computer systems are to be introduced by their offices, since incorrect decisions could have disastrous results.

4.35 So far, it has largely been the case that offices have developed their own computing systems independently of each other. Although some common software packages have been offered on the market, these have tended to have only a limited take-up because of differences between offices for historical reasons, as far as existing business is concerned. It has usually been cheaper and quicker to develop one's own system than to adapt a package.

4.36 However, there are some indications that this situation is starting to change and that offices are increasingly considering the purchase of software packages for work connected with certain types of new business. There is also the point, of course, that software packages of a 'general' nature, such as word processing and spreadsheets, are not worth developing oneself; the packages available on the market are efficient and quite sufficient. Possibly we might see further developments in 'common' software packages which could be used by the industry as a whole. Much work has already been done by the Aries Club in the pioneering development of 'expert systems' as applicable to insurance, and the initiative is about to be continued at City University. It could well be that such software packages will be in fairly general use in 10 years' time, though each Office will no doubt wish to make its own modifications.

4.37 Our enquiries about expert systems in general, not specifically those mentioned above, have led us to believe that they are still at an early stage of development, without any capability of learning from experience. It was emphasized to us that there is a need to keep one's feet on the ground when designing an expert system. It should be developed in stages, not as a fully comprehensive system, and its objectives should be fairly limited. By way of example, we were told of a successful system which a computer manufacturer developed in 1986 to identify the faulty components in newly-manufactured computers which were malfunctioning—this system apparently achieved a 93% success rate. Another system involves the automatic detection of insider trading on the New York stock exchange. There is little doubt, however, that expert systems will become much more complex, useful and widespread as the years go on.

4.38 One of the questions we have touched on, in reviewing the historical developments of calculating devices, is whether the actuarial profession has responded quickly enough to new technological developments. For example, the arithmometer was invented around 1820 but did not find its way into the pages of *J.I.A.* until the 1870s, and in spite of its existence, logarithms continued in use in some places until the 1930s and multiplying tables until about 1950. Similarly, with the introduction of computers, we have seen on the one hand that some offices have restricted themselves to applying the new computer power to administrative tasks, whereas other offices have seen the potential that is now offered for the first time and have developed complex model office programs. One cannot say that those who lag behind are necessarily wrong, since they have no doubt taken account of a range of considerations, including financial constraints. Looking to the future, however, it does seem that the actuarial profession needs to be particularly wide awake to new developments in the next few years.

The Longer Term Outlook

4.39 If we look beyond the next 10 or 20 years, is it possible to visualize computing devices which will accomplish tasks which are at present almost beyond our dreams? It was only just over 50 years ago that E. W. Phillips suggested in his Institute paper that it might one day be possible to carry out 40,000 multiplications per hour! We have come a very long way over the last 50 years and one cannot resist speculating about the future over a similar timescale.

4.40 Might it be, for example, that computers will be able to learn from their past 'decisions' to a much greater extent than at present? Might they be able to take account of a much wider range of data related to happenings in the world, such as the data (both statistical and non-statistical) we assimilate at present through the daily press? Might we find that communications between humans and computers are vastly improved, so that instructing the computer becomes almost as easy as instructing a member of one's staff? Perhaps communications in all walks of life will become so 'instant' that virtually all time lags become a source of annoyance?

4.41 Maybe computers will develop skills in pattern recognition which will enable them to take 'judgements' based on a wide range of considerations?

4.42 In considering the future rate of change, we need to ask ourselves what are the likely constraints. Perhaps people are only capable of assimilating a certain rate of change and beyond that all kinds of difficulties occur. Moreover, can economic systems adjust so that they cope with rapid change? Could we find perhaps that attempts to change too rapidly could lead to pressures building up inside the system, and sudden catastrophes?

4.43 In an attempt to answer some of these questions, we sought views from several eminent people in the universities and in the computer industry, and we are most grateful to them for their assistance in helping us to look forward over the longer term.

4.44 The main developments which can be foreseen in the next 15 to 20 years are as follows:

(a) Increasing speed and wider distribution of hardware, together with improved memory capabilities.
(b) Databases which are increasingly linked up and become increasingly capable of prompting action autonomously.
(c) Development of expert systems and, possibly, other artificial intelligence applications.
(d) Systems which are more 'user friendly'.
(e) Increasing speed and efficiency of communications.
(f) Increasing availability of standards, and standard-conforming packages, for communications, data storage, graphics and office functions.

4.45 Some of these developments are already starting to happen and significant progress is likely even within the next 5 or 10 years. For example, the spread of 'electronic publishing' will enable reports with good-quality format to be produced much more quickly than at present. Moreover, the output from computers will increasingly be presented in easily assimilated graphical form, thus making the output much more usable by senior managers.

4.46 There is likely to be a significant speeding up of the rate at which computers operate, and this could facilitate a number of applications which are at present constrained by relatively slow running times. There will also be more connections between different computers and a linking-up of data banks. In 10 years' time we shall see expert systems which are integrated with databases, and increasingly 'active' databases. These expert systems will often have flexible rules of connection rather than the rigid rules which are usually employed at present.

4.47 A technical development which is likely to come into practical use is 'parallelism'. A number of processing units (perhaps thousands) will work together simultaneously and link together as they work. A number of parallel jobs can therefore go on at once and the speed of the total system will be limited only by the critical path. There will be more autonomy between different parts of a computer system, so that if one machine fails, the whole system will not break down. The new technology will be largely invisible to the end user, but it will assist in increasing speed and reliability.

4.48 Another technical development over the next 10 years may well be the introduction of a new style of computer hardware, which will not only do numerical calculations quickly, but will also run symbolic applications much more quickly than is at present practicable. Numeric programs are those commonly in use today, written in FORTRAN or COBOL, which do scientific and commercial calculations, and straightforward administrative tasks. Symbolic programs are less familiar, written in languages such as LISP and PROLOG, and they help with tasks requiring judgement and qualitative reasoning. Numerical and symbolic programs will start to be integrated. Computers will then be able to deal with data structures as well as numbers, and steps will not necessarily have to be taken in the rigid sequences that are necessary at present. This will assist in the development of expert systems and may also be helpful in the development of 'artificial intelligence'.

4.49 One of the main problems is going to be the process of changing from current systems to the new systems. How can one build on what has gone before, rather than starting again from scratch? Historically it has always been possible to do this, but often only with considerable difficulty, sometimes leading to great rigidities in the system during a changeover period which has lasted several years. Since standardization is still in its infancy, we are likely to experience similar obstacles in at least the next round of major changes.

4.50 It will become easier in future for people who are not experts to find their way around computer systems and be helped over difficulties in using terminals. Such people will be able to feed in their questions through the keyboard in ordinary language and the computer will be able to dissect these questions and provide potentially helpful answers. Programs will be developed which will be able to distinguish speech and the different styles of individual users; people will be asked to speak a set of key words, which the machine will then use to 'recognize' other words spoken by the people concerned. The latter facility is available now and elementary applications may become commonplace quite soon. However, a more comprehensive interpretation of speech, including semantics, is at least 10 or 20 years away, as there are many difficulties to be overcome.

4.51 It seems likely that, at a later stage, practical ways will be found in which computer systems will be able to 'learn', in order to provide better predictions of future events. For example, let us consider Mycin, a pioneering expert system which was developed to diagnose and recommend treatment for bacterial infections in the bloodstream, and has been shown to have a good performance record relative to specialist diagnosticians. The system's expertise lies in the explicit use of diagnostic rules derived from leading experts, which link patient characteristics and symptoms with infecting organisms and drug treatments. During a Mycin consultation, details of a patient's symptoms are fed into the computer, which produces a list of the possible infections which the patient may have (with a 'degree of likelihood' attached to each one) and the appropriate drug treatment for each. To give Mycin a learning capacity, details could be fed in of the diseases which patients had actually been found eventually to have and the accumulation of such data could be used to modify the probability distributions previously built into the system about the degree of likelihood of a given set of symptoms being attributable to a particular disease. Such 'learning' might well be of a purely mechanistic nature, based on counting the numbers of cases in particular categories and gradually modifying the built-in probability distributions, having regard to prescribed criteria for determining the degree of significance of deviations between the 'actual' and 'expected' experiences.

4.52 There are several other types of 'learning' found within the field of artificial intelligence, another example being where the learning process involves the gradual acquisition by the computer of a wide range and large volume of data which is considered relevant to the matter under consideration; this historical databank is then interrogated in order to identify past situations which are analogous to the present situation, in the hope that useful conclusions can then be drawn. The past situations need not be precisely the same as the present situation: the computer identifies which ones are nearest. It may also eventually be possible to infer general 'rules' about observed phenomena.

4.53 How is computer learning most likely to progress? We were told that workers in this field take the view that "you cannot really learn anything unless you almost know it already". This is the principle which is likely to guide the practical application of artificial intelligence concepts. Rather than expect the program to think entirely for itself, the best practical results may well be obtained in those cases where the information fed in is based on the knowledge and experience of experts, before the program gets down to work. Thus, for example, if one is seeking the general rule governing observed phenomena, it might well be better to feed in an approximation to the rule, based on experience, rather than expecting the program to devise the rule entirely by itself.

4.54 The techniques which are necessary for 'inductive inference' are now quite well established, but they have not so far been applied in practice in large-scale real-life situations. Before this can be done, it is necessary for users to build up databases which are constructed in new ways. The data needs to be 'annotated' by experts each time it is fed into the computer. The annotations will indicate particular aspects that appear to be relevant to the data in question, including possibly an assessment by the expert of possible future consequences arising from the data. Clearly it would often take a number of years to build up such databases. It is this 'time lag' which suggests that long range planning by potential users of 'inductive inference' techniques could pay dividends. The time may be approaching when serious consideration should be given to starting to build up relevant databases, even before the necessary computer equipment for practical application of the techniques is available. Moreover, the building up of the databases could well provide the impetus for the further development of the techniques and hardware. Although it is still not clear exactly how such artificial intelligence techniques will be applied in practice, the long term potential is probably very considerable.

4.55 Even where the use of databases mentioned above is not considered worthwhile, there is likely to be a much greater use of the 'corporate database' approach, where all relevant data are maintained on the computer system and are accessible for all calculations. Trends in the recorded data will be continuously monitored. When predetermined trigger points are reached, 'alarms' will be signalled or, in some circumstances, prescribed executive actions will be taken.

4.56 It is indicative of the increasing interest in artificial intelligence techniques that, as this report was being prepared, a £1 million plan to try to find out how the human brain manages to perform calculations was launched by the Science and Engineering Research Council (*Daily Telegraph*, 2 September 1987). It was reported that by making 'neural networks'—which are highly interconnected electronic circuits reflecting the way nerve cells interact to solve problems—scientists hope to mimic how the brain processes information. At the same time it was proposed to delve further into an important area now known as 'molecular electronics', which could lead to improvements in computer technology. A further report on these possibilities appeared in an article in the *New Scientist* of 26 May 1988 (page 61) by Michael Recce and Philip Treleavan, where it is stated that, in place of explicit programming in the form of a series of commands, the programmer trains the neural networks by feeding in patterns. However, the prospects for success in this field are very hard to predict.

4.57 In the longer term, it might even be possible for computers using biological components to be developed, which could imitate the human brain. The recognition of complex patterns might then become more practicable, and this could lead to computers taking a leap forward as an aid to management.

A Role for the Institute

4.58 It is for consideration whether it would be worthwhile for a standing committee of the Institute of Actuaries to be established in order to study likely future developments in the computer field, so that suitable fields of application in actuarial work can be identified at an early stage. Such a committee would include representatives from the universities and the computer industry. The continuing work done by the committee would probably be helpful both to the computer industry and to members of the actuarial profession, as well as helping to strengthen the position of actuaries within their Offices, when decisions are made about future extensions of Information Technology.

4.59 We have ourselves tentatively identified some possible fields of application in the long term, as follows:

(a) Identifying the factors which are present prior to major changes in interest rates or stock market price indices, so that predictions can be made of future changes in these items.
(b) Constructing expert underwriting systems which 'learn' automatically from the actual experience of the cases which have been underwritten, so that more accurate weightings can be attached to the various factors in future (for both life assurance and general insurance).
(c) Linking the mortality and sickness experiences of the same group of lives, with a view to establishing whether sickness patterns can be regarded as mortality predictors.
(d) Constructing more complex model office simulations, which will portray more accurately the interaction of a number of future activities going on simultaneously—this could even include simulations of the market place as a whole.
(e) Modelling complex legislation, e.g. on pensions or social security, with a view to identifying constraints on proposed courses of action. Such a system could also identify automatically the parts of one's own system which are affected by proposed or actual legislative changes. It might even become possible for the computer to attempt some quantification of the effect of the changes, for example in terms of the number of individuals within one's own system who could be affected in the course of a year.

Conclusion

4.60 The present generation of actuaries is uniquely placed to see both the old methods and the new. Within the scope of a single career some people have progressed from carrying out calculations by hand, using tables or slide rules, to carrying out much more complex calculations by the use of computers. It has, therefore, seemed worthwhile to capture such a wide range of experiences while they are still fresh in people's minds (and a file containing detailed notes of the interviews, and other relevant material, will be deposited in the Institute's library). We have also given some pointers to possible future developments, which we hope will stimulate discussion within the profession, and have put forward a suggestion for a possible continuing role for the Institute in this field.

5. DISCUSSION POINTS

5.1 Some of the questions which, we suggest, might be particularly suitable for discussion are as follows:

(1) Are increasingly powerful computers leading to unnecessarily complex contracts? (3.31, 4.5, 4.6)

(2) What effects are computers having on actuarial departments and are there, as a result, new problems in the training of actuarial students? (3.37–3.42, 4.31–4.33)

(3) Do computers present us with new opportunities in the 'wider field'? (3.42, 4.22)

(4) Will there be serious problems in upgrading today's computer systems? (4.7, 4.49)

(5) How serious are the data security problems likely to be? (4.23)

(6) Will better electronic links lead to further changes in the 'head office-branch-agent' organization of the life assurance industry? (4.8, 4.10–4.16)

(7) Will 'home computers' become an important factor? (4.12–4.14)

(8) What future is there for 'expert systems' in our work? (4.16, 4.37, 4.51–4.55, 4.59)

(9) Will computers present us with new opportunities to carry out investigations we would have liked to make previously or to develop improved theories? (4.30)

(10) Will computers give rise to increased external requirements, e.g. in relation to legislation, Government statistical returns or more onerous demands from clients? (4.17–4.22)

(11) Do we need new actuarial techniques, e.g. to place approximate checks on computer answers, or a new actuarial notation? (2.25, 4.24–4.26)

(12) Will 'model offices' play a key role in future? (3.30, 4.27)

(13) Will computers fundamentally change the task of actuaries, and if so, do we need to change the qualifications for entry to the profession? (4.28)

(14) Is there a danger of being overtaken by other professions? (4.29)

(15) Is there scope for more 'common' software packages in our work? (4.36)

(16) Is there a real problem in keeping up-to-date with changing technological developments? (4.34–4.38)

(17) What is the longer-term outlook? (4.39–4.57)

(18) Is there a need for a standing committee of the Institute to study likely future developments for the benefit of the profession and to communicate our views to the computer industry? (3.47, 4.58, 4.59)

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'On the Mortality among Assured Lives and the Requisite Reserves of Life Offices. Part II, Financial.' *J.I.A.* **20**, 233.
'On the comparative Reserves of Life Assurance Companies according to various Tables of Mortality, at Various Rates of Interest.' *J.I.A.* **37**, 453.
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ABSTRACT OF DISCUSSION

Mr R. D. Campbell (opening the discussion): With some notable exceptions the profession has been rather slow in taking up the recent advances in machines and computers and I was surprised to discover from the paper that we have been slow in the past. The authors record in §3.11 that logarithms completely dropped out of use in practice during the 1940s. However, I remember that the Institute responded rapidly to that and they ceased to be compulsory for exam use as early as 1977.

I agree with the authors when they make the point in §4.38 that the profession needs to be wide awake in the future. Their proposal for co-ordinated central action will be a necessary part of that. I would not go along with the suggestion of forming a committee to tell the computer people what we want. I think it would be better to tell actuaries what is on offer and how to make the best use of it.

The paper is mainly about computers and rightly so; much is about the administrative considerations for life offices. I am a great subscriber to the view, "to err is human, but to really foul things up requires a computer". Administratively we are not very good yet. What about data integrity? If I had been speaking 5 years ago I would have said that this was a major concern for my office. How do we make sure it is right? How do we make sure that each client is on the computer only once, that we have all his details in the same place and that if he moves we remember to update all our data in one go? The impression I get is that integrity has improved quite dramatically and it may be that the administration is going to get much better through the use of computers, but I am not entirely convinced, certainly from experience as a consultant, that these problems have yet been solved. In recent years computers have given us the power to develop and extend actuarial theory and models dramatically, in the same way that present techniques developed from a sudden ability to do a great deal of computation quite easily. Computers are giving us back the actuarial high ground. They are giving us the opportunity to develop new theories, to pursue new ideas and to operate on better information. Cheap power is available to all actuaries. We have a tremendous opportunity to take actuarial thought and actuarial theory forward.

The first question at the end of the paper suggests that increasingly powerful computers may lead to unnecessarily complex contracts. I hope that this will not be the case because it is a sure-fire way of giving away our market-place to others who are more conscious of what the market wants.

Question 2, which asks about the effects computers are having on actuarial departments and the training of actuaries, is linked to question 13 on the role of actuaries and professional entry qualifications. In the end employers decide who the best people are and the entry qualifications are there as a safety net. What is a primary concern is progressive reform through employers and through the training that the Institute Education Service gives to students.

Question 3: Do computers present us with new opportunities in the 'wider field'? In my view they present us with a tremendous opportunity to be more actuarial, to develop new models and theories. Looking back over the Institute's *Journal* for the last three or four years I see a number of outstanding papers which have developed that idea. They have been used to develop some very sophisticated models, particularly in the area of investment. Computers also give us a tremendous opportunity to work with statisticians, economists and to explain and demonstrate our perspectives as actuaries.

Question 4: Will there be serious problems in upgrading today's computer systems? 'Serious problems' is a relative term. Problems that we see now as very big in upgrading computer systems would have seemed less important in the 1970s and I am sure that 1990s size upgrading problems will not be as big as the ones we face in the 1980s. Change is always difficult to manage and upgrading systems is about managing change, not about technical difficulties. In the past people hung on to elaborate manual calculations, no doubt because it was expedient to do things that way: a job had to be done. We must not lose sight of the fact that calculations themselves are not the end but merely a stage in what we are trying to do.

Question 5: Data security problems will become a big issue if and when serious mistakes occur, particularly with increased interest in underwriting of life assurance.

Question 6: Will electronic links change the life assurance industry and its organization? This is linked to question 7. 'Home computers' will change the market place and will change the lives of actuaries. Teleworking for actuaries is a serious possibility.

Question 8: 'Expert Systems' are here now and will grow at a great rate through the 1990s with tremendous possibilities.

Question 9: Will computers present us with new opportunities to carry out investigations we would have liked to have made previously? They have and will.

Question 10 I considered as being very negative. I am delighted when my clients demand things, particularly if this means that they are becoming more interested in actuarial services.

Question 11: Do we need new actuarial techniques to check things? I no longer undertake calculations without an actuarial student at my side, and I no longer undertake checking them without at least three actuarial students at my side!

Question 12: Will 'model offices' play a key rôle in the future? The reason model offices are valuable is because they enable you to make the best use of current information. Computers enable you to make the best use of what you know now. You cannot predict the future, but you can see the effects of current information. Projections of all kinds, be they in the pension funds field, in general insurance or in life assurance, are going to be enormously important. We now have cost-effective computation techniques which allow projections on a much more detailed basis over a longer time scale than ever before.

Question 14: There is a danger of being overtaken by other professions. Statisticians have possibly stolen some marches on us in the investment field and I think there is a danger of that happening in other fields. For the same reasons that we are able to explain ourselves to other professions through the use of computers they are able to challenge our methods and our approaches through the use of computers.

Question 15: There is more scope for common software packages, there is scope for adapted spreadsheets. We have got to find a way of paying for them. The Institute should be funding some projects of this kind, or collecting funding from the industry. It ought also to take on the rôle of co-ordinating information for the profession about what is happening in the computer industry.

Question 17: What is the longer-term outlook? I do not think we will ever know, but the profession ought to be in the position where it can take advantage of whatever becomes available.

Mr G. B. Hey: It is 53 years since I started using the Monroe and the Hollerith machines shown in the illustrations. The paper described some of the older machines, but there are two which were not mentioned, which I think are quite interesting. One was the Millionaire which had built into it a metal body which comprised a multiplication table, so that one turn of the handle multiplied a number by any digit from 1 to 9. The other was invented by Mallock at Cambridge and consisted of a bank of 110 transformers, each of which had 1,000 turns, so you could set any number from 0 to 999. It would solve a set of ten by ten simultaneous equations. As far as I know the National Cash Register machine was never used in table-making except for differencing and for sub-tabulating.

I got the impression from the paper that the authors thought that the profession had neglected punched-card machines from the middle 1930s to about 1950. They were very flexible machines in some ways, but not suited to actuarial calculations, as agreed by Professor R. E. Beard. Just to give you some idea of the inversatility I used one of the English machines in 1937 to do 2,000 simulations of an analysis of variance to produce sums of squares and differences and the F-ratios. It was by no means the first application of simulation, which goes back to about 1912 when Gosset did it for calculating the t-distribution, but as far as I know it was the first time for punched-cards. We used a machine in 1944 to produce about 500 pages of tables for bomb aiming for the American Air Force. In 1945 we used an American version of the machine to obtain the crystal structure of penicillin. The calculation involved about 4 million sines and cosines, multiplying them together and adding them. This gives some idea of the flexibility of those machines.

In the paper it was suggested that very little was done in the 1970s and the authors never mentioned general insurance, but general insurance is now part of the actuarial profession's work and in the 1970s there were enormous advances in the use of computers in general insurance. Probably more computing is done now in general insurance than in life assurance. There were four working parties in the late 1970s; I was chairman of the one trying to devise packages. Everybody was willing to give their experiences, but nobody was prepared to listen. I am still convinced that to go back to first principles is the only way of proceeding, as is happening now for a large number of pension fund calculations. There are standard packages, but mostly they go back to first principles, on which series of subroutines are written, onto which parameters are stuck. One problem suggested is that there are too many parameters, but I am convinced that useful packages could be written without too many.

The authors want to talk to computers in plain English. The way to talk to a computer is to let the computer ask the questions and you supply the answers.

The DTI raised legalistic objections to the provision of information in computer form when I suggested it in 1970, but it is obviously desirable to cut out the enormous stack of paper that comes from every insurer each year.

I am not so sure that PCs are user friendly. At the office I had a suite of about 20 programs and every month I wanted to run about 5 of them. I had written them in such a way that all I had to do was to give the data processing department 5 cards with the names of the programs and perhaps some initial data. My FORTRAN program then wrote another FORTRAN program. All that had then to be done was for the 6 cards to be put into the machine and it then wrote the program, compiled it, linked it, ran it, spooled the output onto disk, sorted the disk by the program and printed the output. Nothing ever went wrong. That is what I call user friendly.

Are we locked into our systems? Of course we are, until somebody changes their minds and is prepared to admit that something could be better. The computer does not forget, but it only remembers what we tell it.

Mr J. D. Harsant: The availability of ever more powerful software has followed the increasing power of computers. Whilst most of the existing applications are written in one of the procedural languages, usually COBOL, it has been found possible, by using the power now available in modern computers, to dispense with much of the tedious details which accompany the use of these languages. This has given rise to the so-called fourth generation computer languages. The most significant development here has been the adoption of the ANSI standard SQL which is used in conjunction with a number of relational databases. These are proprietary products and have mostly been developed in conjunction with mainframe or minicomputer systems. The most useful of them have substantial facilities for reading data from files maintained in a computer system, no matter how these files were created in the first place. They also allow calculations to be made either within SQL or by calling routines in a procedural language such as FORTRAN. I emphasize the use of relational databases, for although the work of actuaries is computational, the prerequisite is accurate data.

The use of an international standard such as SQL must assist in prolonging the life of systems which use these standards. The computer environment in which these relational databases often run has a very demanding machine capacity requiring, perhaps, several megabytes of main memory together with a great deal of processing power to carry out the overheads associated with this particular language. If you are not prepared to work out the tedious details then the computer requires a lot of power to do it. Thus, in the first instance, their use was mainly, but not exclusively, confined to the larger mainframe machines. The advance in computer technology has been such that the power of the desktop machine is now so great that all these systems with their great demand for power can be used on micro-computers without difficulty.

As an illustration of the power and cost effectiveness of these machines Figure 3 shows the power of a 32-bit microcomputer in 1987 as 1 million instructions per second. The machine which I currently use most has a power of 4 mips. It has a main memory of 2 megabytes and cost me £2,000. This machine runs a relational database which I believe to be one of the most advanced and demanding in terms of machine capacity. I was interested to read in the *Financial Times* recently that DEC had announced that they could now provide a mips of power for $30,000. Although a micro is a very different machine you can see that a mips only cost me $1,000.

From time to time there have been occasions of significance in the development of computers and I cite as examples the following:

(a) The general availability of disk technology and the procedural/third generation languages in the late 1960s.

(b) The introduction of interactive computing in the mid 1970s.
(c) The introduction of the business desktop computers in this country, in about 1982.
(d) The current availability of powerful desktop computers complete with the most powerful software tools yet known.

I believe that with the coming of these fourth generation languages we are on the edge of the next major step foward in computing. The benefits of this will only be achieved, in my view, provided that there are two basic criteria met. The first is the correct managing of computers. In some companies even today, and I am referring to industry as a whole, data processing is not really understood by the top management. They are perhaps afraid of it and keep it at a distance. The effect of this on a company can be serious, it demoralizes the computer staff, puts up a defensive attitude amongst them and mitigates against the interest of the company as a whole. The other point is that just to have computers and the excellent software which goes with them is not enough. To make proper use of them one needs to make use of the highly developed methods of systems analysis which are still largely ignored by many people. Everybody ought to set out their work using a technique of structured analysis before they get anywhere near a keyboard.

Once we have developed techniques for using these tools, what are their uses? I have already put mine to good use to solve a problem, which at one time I thought was intractable; that is being an actuary to a Friendly Society Order in decline. I have been able to put in systems for the maintenance of their records and use the data thus collected for the purpose of the quinquennial valuations within a time and cost structure that is pleasing to all concerned. There are many companies who would like to maintain their own pension records. Some have written their own systems, many others seek a propriety solution. There are proprietary solutions around, but none appear definitive. These structured techniques provide a way forward in this area.

Mr W. T. L. Barnard: I am disappointed that there is very limited reference to the ingenuity of actuaries in developing systems for the equipment available to them at various times. I have in mind particularly Perks' 'Two-Variable Developments of the *n*-ages Method' (*J.I.A.* **72**, 377) and Joseph's. 'The Valuation of Whole Life Assurances by the use of Moments' (*J.I.A.* **72**, 498). Since we had Power Samas equipment in 1918, papers in 1948 were a full 30 years late in taking advantage of the equipment that was available. We are not now quite so slow in taking advantage of the new facilities available. I wonder what the future is for commutation columns? It may well be that we no longer need these in our science in the future. I would point out that the English Life Table Number 12, published in 1968, was produced on a 4K IBM 1401.

As for the future, there is a tendency to use the computer as a substitute for thought and this is something which I would like reversed. Our younger actuarial teams should bear in mind that the computer will only do what it is told and they have to make up their own minds in the first place as to what they want done. As we develop with our desktop computers we are in danger of finding that, with changes in equipment and with changing staff, the methods and bases which were used to arrive at conclusions have been lost inside the computer data processing systems and nobody will ever know how they were reached.

Mr S. C. Stoye: When a program has been written I find it very reassuring to be able to check the factors it produces against published ones. If only mortality rates or equations for q are published in future, as suggested in the paper, this will be impossible. We do need something to check against. The Institute should publish enough sample values for checking, or have a database of them in the Library. There are various services that the Institute could offer. Do we have any plans for an electronic library that I can access for my PC? When will the Institute's papers be distributed by downloading a file? When will meetings be held by electronic mail, or on a bulletin board?

Expert systems were discussed, mainly in the light of making people able to carry out more skilled tasks. They also have a rôle to play in spreading knowledge. Knowledge acquisition and knowledge database technology from expert systems will change the way the experts work. We are not good at recording our expertise and passing it on to actuarial students. Knowledge databases should help. Text databases and text retrieval programs are improving and there is a new category of programs called 'Personal Information Managers' emerging. Hypertext may prove useful. All these technologies will be relevant to the Institute Education Service in future.

Computerizing actuarial notation was discussed in the paper. This is a huge subject that concerns not just the factors, but also how data are held and how the factors interact with the data. This is complicated by the wide range of calculations we do these days including modelling offices and stochastic analyses. Computers enable actuaries to use new techniques; an example is the use of emerging costs. A standard for data transmission is also needed, for instance when new premium rates are sent to branch offices. A computerized notation would have to cover all these areas as well as overcoming the problems mentioned in the paper. The authors do not really cover the subject of software productivity. Progress to date in this area has been disappointing when compared with progress in hardware. A vast amount of software needs not only to be written to achieve the possibilities outlined in the paper, but also checked, documented and maintained. At the current rate of programmer productivity and with our current programming resources this will take a very long time. One influence on this productivity is the quality of the tools available to programmers. We must ensure we use the best tools available and encourage the computing industry to produce better tools. The future of programming languages was mentioned. I agree that numeric and symbolic programming will merge, but this will take a long time. In the meantime changing programming technologies will have an enormous impact on users. Will a paper in a hundred years time say that COBOL was used for 50 years too long? What will replace spreadsheets and when? The answers to these questions will affect programming productivity which is a vital factor in future computer use.

We should discuss the availability of actuarial programs and eventually our knowledge of databases to non-actuaries. This will happen as more packages become available. We must ensure we maintain our skills in interpreting the answers and our skills in producing such packages. The presentation of numerical results, not only to others, but also for ourselves to check and to understand the numbers, needs to be developed. The authors mentioned graphics; another possibility is animation. I wonder whether sound has a rôle to play too? How will we use three-dimensional graphic output devices when these become widely available and cheap? Home computers must catch on in time, but perhaps they will be produced by the entertainment industry and not by the computer industry. They will get a boost when high definition television becomes readily and cheaply available. Perhaps we should have had representatives here from the entertainment industry so that we could be sure that their computers will connect with ours. It would be very disappointing in this age of standards if there were to be a gulf between business computing and future entertainment computing in the home. Finally, it is becoming impossible to keep up-to-date with computing and pensions and still find time to do any productive work.

Mr C. D. Sharp: In 1928 I joined the actuarial department of Gresham Life, which had wide overseas business and, therefore, an extensive actuarial set of problems. We had one hand-operated Brunsviga which was reserved for the assistant actuary. By 1939 we had obtained quite a number of hand-operated and electrical machines, but we certainly had not got as far as punched-cards. During the War years I was working in India and became conscious of the fact that we needed a set of actuarial tables based on Indian mortality. A set of mortality rates had been produced, but the tables simply were not available and certainly there were no facilities to do it by hand. Use of a multiplying punch resulted in the $0(25\text{-}35)$ tables which were published in 1944 and became the standard in India for many years.

It was, therefore, surprising that 9 years later in the standard tables produced by the Institute virtually everything was done by hand. In 1950 through a contact at the National Physical Laboratory I was able to try an experiment with the older ACE computer, a 'Heath Robinson' type of thing. From punched cards we valued a group of endowment assurances. I asked a number of senior actuaries to come and see this demonstration; one said "I do not think computers will ever do anything for life offices!" If he had said that *that* computer would not have done very much he would have been absolutely right, but none of us could visualize what was going to happen in the next 10, 15 or 20 years.

Professor R. M. Needham (a visitor): The point I wish to make is concerned with security and integrity. There are some signs in the paper of a degree of neurosis about this subject which tends to afflict computing people and, in particular, in subjects where computing is just taking hold. Often these things are greatly over-rated. If you take security very seriously, it is possible to tie yourself up in knots so that you cannot do anything. Security is all about stopping people doing things. The aim is not to make sure that your computer system is totally secure, but that it is no worse than what you do now. This applies also to integrity of data. I suggest that the odd bit of broken data cannot hurt very much if you are dealing with averages of a great number of things.

I do not know what the security problems of practical actuarial work are now, but I am confident that if you try to do a great deal more something awful will happen. People concerned with computers in hospitals get extremely worked up about the security of data, but if you propose measures which will go anywhere near achieving what they want to achieve the hospital will never mend any body ever again. It would just be too difficult to get everything organized. I am not proposing carelessness, I am proposing something I suppose to be acceptable to this audience—a proper balance of risks rather than going over-board. It has been said that computers are no substitute for thought. I would like to suggest that thought is no substitute for computers because only people can think and they are much more expensive.

Mr M. R. Granville: I am having an argument at my son's school—they are very keen on computers but they want to teach him assembly language and BASIC, I want them to teach him typing, how to use spreadsheets and word processing. The thing I find most frustrating about using computers is not being able to type.

Will computers change actuarial work? I hope so. We still tend to work with central values and expected values, but spreadsheet packages now allow probability distributions to be assigned to some or all of our variables. For example, if you are running a model office it will show you a likely spread of results into the future; an illustration of Redington's famous 'expanding funnel of doubt'.

Life office administration packages are a major disappointment. In my view it is almost impossible to upgrade from an office's own system to one of the life office packages currently available. The best that can be done is to put new business onto the package and leave existing business on the old system.

If I was wanting to develop computer systems for a life company today, I would insist that a senior actuary was the chairman of the committee that implemented the new systems, and that he had his sights firmly fixed on the quality of the data.

Mr P. J. L. O'Keeffe: The authors have been somewhat less than fair to those of us who worked in the 1970s. The one big development of the decade was time sharing. A manufacturer with a large capacity computer would allow people sitting in their offices to tap into it using modems and telephone lines. Using this time-sharing system some of us developed profit-testing techniques and model offices. At that time the languages available were FORTRAN and BASIC and I looked in vain for any mention of BASIC in this paper as a language used by actuaries.

I wish to reiterate the worries that the authors have had on the education of actuaries. There is no doubt that those of us who saw the end of the era of hand-cranked machines and were expected to set out work in a neat and logical fashion, developed an understanding for the way that a table of rates moved and the way everything hung together. These days actuarial students prepare data, feed figures in and get the results out, but they do not always understand the results. Computers have already had a huge effect on our working lives, not only in making arduous jobs such as valuations simpler, but also in opening up whole new areas of business. It cannot be pure coincidence that the growth of unit-linked business has coincided almost exactly with the development of computers. Some actuaries must have had the bright idea of keeping each policyholder's individual premium and allowing it to participate equitably in the total fund prior to the advent of computers, but they must have blanched at the amount of calculation involved. Equally there are now many more facilities open to policyholders such as switching, options, policy reviews and variable charges which could only conceivably have been administered by the use of computers. Indeed I remember learning that one prime recommendation of the net premium valuation method was that each policy record card could just have two factors assigned to it at inception and from then on enormous groupings made the valuation simple. Would anyone starting from scratch today have come up with the net premium method as the official statutory method of valuation?

A more recent development is for life assurance companies in this country to publish results which include embedded values, either as an indication of the worth of the company, or as an additional element in the profit or loss account of a non-assurance holding company. As an Institute we should welcome this development. Calculations of embedded values and embedded profit are only practically possible with the use of large and high-powered computing facilities. At present the tendency is for these values to be calculated using model offices. This work involves finding model points which represent the business in force, calculating the value of future surplus emerging from them, weighting them by the actual business in force and hence producing the value of future anticipated surplus. There are many bright minds currently involved in designing systems of rules which will govern the calculation of embedded values, but it does seem to me that, in calculating embedded values using models, we are going through a classic actuarial cycle as described in this paper. We see that the tools available allow us to make use of the concept, then we look around for ways of making the actual practical calculations of that concept simpler. So we say that calculating the values of future contributions to surplus of each individual policy it too big a job. How can we find ways of doing it using models of representatives of the data? If computers get big enough and the number of calculations that can be handled gets large enough, there is absolutely no reason why we should use models. Models are extremely useful for viewing the future track of an office, but calculating embedded values seems to me not the right purpose. If we can calculate anticipated individual cash flows on each policy for valuation purposes then we can derive future surplus movements on each policy and from that we can calculate the future revenue accounts. Even if your office has 10,000 or a million or 10 million policies you will still, given the almost unlimited power of modern computers, be able to calculate the embedded value. Computers are already so fast that the amount of calculation required to do any job is no longer a factor which needs to be considered.

As a profession we must ensure that we can still see the wood for the trees, and that machines are used to serve us and not the other way around. We must use them and we must make sure that our members, whether young or old, junior or senior, keep a firm grip on reality rather than become mere feeders-in of data.

Mr P. J. Turvey: Mr O'Keeffe mentioned the use of time-sharing in the 1970s; that was a very important development. Until about 1970 the only actuaries who were ever able to use mainframe computers were those who had access to a machine in their office's data processing department. The advent of time-sharing either on the office's own machine, or more usually on a bureau's, made computing available to hundreds of actuaries. This was a key event in the development of actuarial computing.

Another important development of around that time, which I was sorry not to see in the paper, was that of the various actuarial programming languages. I mention ACT, which was developed by Geoff Humphrey, and Sidney Benjamin's columnar manipulation techniques. A program called RIVAL was developed by ICL and was, I understand, widely used, and another language, also called ACT, based on APL, was developed by a North American actuary called Jamieson. APL/ACT is still around and seems to be the only language that has survived.

The notation problem has bubbled on over the last 20 years. Much actuarial programming these days uses emerging cost techniques, but the International Actuarial Notation is still addressing the formulae and the methods that were invented in the 19th century. I like the idea of the profession somehow trying to co-ordinate its efforts on actuarial programming, but I find it difficult to know what the professional should actually do. The authors list five different areas for possible applications in the long-term, but all of these are problems that are driven, not by the use of computers, but by whatever the particular business problem is. We must not lose sight of the fact that computers enable us to solve problems—they are not a problem in themselves. The authors make a number of references to real-time computing. I do not think that actuarial computing will ever become real-time. As computers get more sophisticated our questions, as in the past, will become more and more difficult. As I understand it expert systems tackle the problem of scarce experts who are confronted with the same problems day after day. To use expert systems effectively you need a repetitive problem, otherwise it simply is not worth the effort of building the system. In much actuarial work this type of problem does not arise.

As to the future I see three key challenges for the profession:

1. To enable the actuary in a life office to access the whole of his office's database in a relatively easy way, so that he can carry out mortality investigations, lapse investigations, etc.
2. To help actuaries, and indeed managers, of life assurance companies manage the installation of new computer systems or the revision of existing systems.
3. To improve programming productivity. We have seen huge increases in hardware productivity. On software productivity I do not think that the average output of an actuarial student has more than (say) doubled or trebled over the last 15 years as a result of the introduction of languages such as ACT and so on. The real challenge is how to get a great deal more productivity out of our actuarial students.

Mr G. F. Chamberlin: I believe that we learn a great deal from examining our roots and origins, but equally it is also important, having done that, to look forward to the future. Mr Turvey has mentioned the notation problem. That seems to me to have been solved, as computers are quite capable of representing any notation that we wish on the computer screen and then printing it out thereafter. There is, therefore, no need to modify actuarial notation to suit the computer.

I have been involved in the work of the Aries Club and we have been tackling some of the topics which are mentioned in §4.9. I do not think we have been tackling them in quite the same very ambitious terms which are mentioned there. We are certainly constructing an expert system in life assurance underwriting, but it has not yet reached the point where it is a learning system. It is a system which very much replicates the present duties of the life underwriters in examining the proposal forms and the medical evidence which is presented to them. Nevertheless it is a necessary first stage towards a learning system. We have to understand the job as it is presently done and try to represent some aspects of that in the expert system. We would never pretend to represent the whole of the expertise of a top underwriter, but would expect to be able to represent a good deal of that knowledge and certainly all the more routine parts.

Other applications are found in personal financial planning, where whole systems can be devised for the sales representatives to deal properly with customers, giving better service to clients and also ensuring that the compliance procedures are properly followed by the sales representatives of the office.

Modelling complex legislation is an area in which we believe expert systems can be of great value. We intend to begin work on pensions legislation in the near future. Our aim will be to assist understanding of the contents of practise notes, OPB memoranda, etc.

It is the application which should drive the system. Because we have expert systems and the beginnings of artificial intelligence we should expect computers to behave in a civilized way towards us as users. The screen should not consist of computer jargon, but it should give answers in good English and it should enable us to use it as if it was a personal assistant. Recent advances in computer interfaces have made them much easier to use than the typical command line interfaces that we have seen in the past. There has been a tremendous partnership in the past between the actuary and the calculating machine, the actuary and the computer. Expert systems will enable an actuary to use the machine as an instrument not just for calculating but for helping him to concentrate his ideas, represent his ideas, manipulate the data and perform all sorts of logical operations. This is indeed a great future, but it is up to us to say what we want from the computer and not just to be ridden over by the data processing people.

Professor J. Larmouth (a visitor): The paper looks 20 to 30 years into the future, but makes no comments about developments over the next five years. On the horizon is 1992, the European dimension. This will not only mean the possible computerization of returns to the Department of Trade and Industry, but might also lead to returns for different governments and different continental countries, the need for distribution of information to branches around Europe; not just the U.K. legislation but legislation in Europe; not just English life tables but French life tables and German life tables. Are you unique amongst the professions as seeing that there will really be no rôle for computers in helping you to adapt to 1992, or perhaps that 1992 will have no impact on you?

Professor S. Benjamin: The Institute had Working Parties on the subject of the use of computers in the early 1950s. At one time we even tried to introduce programming into the exams. The questions were mostly numerical algorithms, but if a student got a question wrong the examiners did not know whether it was because he did not know how to do the numerical analysis, or whether he did not know how to program. We do not need to teach our new entrants programming any more, but what we should be doing is giving potential actuaries an overview of actuarial work while they are still at university.

In Section 5 the authors raise the problem of approximate checks on large calculations. This is an area of research. When we used column multiplication in the old style the method of average factors did a very good job, but with modern simulations, etc., it may be necessary to settle for checks just on the order of magnitude of the answer. Is it ten times too large? I would suggest four approaches to the problem:

1. We could try to devise or re-invent some approximate methods.
2. We could try sample calculations, by sampling from the population and doing the calculations. This would be a reverse of the suggestion that we do away with model offices: I would suggest that we bring them back so that we can actually check what the results of the massive calculations are.
3. We could sample the calculations. That would be just like auditing.
4. We could aim at methods that would produce upper and lower bounds to the answer.

There is, of course, no real distinction between calculating and computing, but while all calculating is not modelling I would say that practically all *actuarial* calculating is modelling. It is suggested that we will go in for more complex model office simulations. We now have the power to calculate 'forever' in a second. The new subjects of non-linear dynamics and catastrophe theory, etc., indicate that minute changes in initial conditions have large effects on the consequences. What do we do all the calculating for? This leads us to look at the decision process which is actually there to control the system. We never know the initial conditions. We might know the level of items in a balance sheet, but we do not know the rates of change because they are always obtained by averaging the past, so you can only know rates of change at some period in the past and not the current rates of change. If there is no control variable available which is worth simulating, then it is not worth doing the calculating. If there is one, then the focus of attraction is changed to the decision process itself. If we are going to look at the decision process, then there is a place for expert systems. We need to do some thinking before we use a computer even though some of the modern software, e.g. PROLOG, actually helps you to think.

The Futures Committee has in the past tried to co-operate with the British Computer Society. We did not get very far and perhaps there should be more effort from both of us. However, the British Computer Society does now accept that it should be one of their functions to feed professions like ours with assessments of the changing situation. I think we would be glad of their help.

Mr G. K. Aslet (closing the discussion): The Working Party has given us a broad review of the development of calculating devices in the widest sense of that word. Its review has fallen into three main sections: dealing with the past, and some of it is a very distant past; the present and the possible future. Inevitably there has been some overlap between these sections, not least because one man's present can be another's view of the future. Our discussion has concentrated largely on present trends and future possibilities. There were some interesting contributions which dealt with the early history of our subject. Mr Hey told us of working conditions in the 1930s and how punched-card machines and computers were used during his long career. Mr Harsant mentioned the development of interactive systems during the 1970s as did Mr O'Keeffe, who mentioned time-sharing systems. The discussion in the paper on the rôle of microcomputers in actuarial departments appeared to overlook the developments during this period and the growth in networks of inter-connected remote terminals. By the end of that decade at least one office was able to process all requests for routine surrender values and new business quotations live at the branch. One by-product of this development may have been the emergence of the microcomputer and its rôle in actuarial departments as a tool to assist the actuarial student in processing the non-standard enquiry.

The Working Party also drew the interesting conclusion that the use of computers has not generally led to lower administration costs. Perhaps this is due to the increasing complexity of insurance contracts driven by the commercial need to deliver a unique product. The experience of my own office is that unit costs are lower today, because of computerization, than they were 6 years ago. I do not suppose that that experience is inique. I have to admit that the conclusion is largely due to the greater volumes which are being handled today, but these could not have been contemplated without advanced computer systems. The increasing volumes do put pressures on the system and the potential for corrupting the data through clerical error is probably as high as it ever has been. Professor Needham reminded us of the need to keep this problem in perspective. The issue of maintaining and developing any computer system is a real one. Although much effort has been put into providing software and operating systems which do not require a rewrite of existing application programs, this does not resolve the problems posed by the natural ageing of the programs themselves. As business requirements change, often as a result of external pressures, it becomes less easy to amend existing programs. Eventually they have to be completely rewritten. The recent trend towards greater system integration causes problems at this point, since the effort required to rewrite such a system is far greater than for one whose objectives are more limited. The effort required to rewrite a complete system using our current techniques can lead to costs which are beyond the resources of smaller offices. The pressures for greater systems complexity, whether to satisfy product development needs or the requirements of regulators all work to favour the larger players.

The way in which computer systems can be used to deliver the insurance product has received much attention recently. Fixed networks using permanently leased lines might continue to service high volume centres, such as branch offices, but increasing use will be made of commercial gateways, enabling the user to access a number of different central computers. Dial-up systems based on lap-top computers and cellular telephone networks are probably in use already. I remain sceptical about the prospects for armchair shopping for insurance, based on equipment in the consumer's own home, even though a similar system is available in France called MINITEL. This seems to ignore the old adage that insurance is sold and not bought. Systems designed to service existing policies might have a better chance of success. The thought of working from home with a terminal linked to my office's mainframe is an attractive one.

Professor Larmouth also reminded us of the ways in which computers could help us adapt to the European dimension in the years following 1992. Expert systems are still in their infancy but are already in use in the insurance industry, particularly in connection with collecting and giving advice which meets the requirements of the Financial Services Act. We also heard from Mr Chamberlin about the progress of the Aries Club projects covering life assurance underwriting and pensions legislation. Whether any of these systems can become sufficiently 'expert' to supplant the real expert, rather than just to make his skills more widely available, is, of course, another question.

This discussion leads naturally to the subject of the actuarial profession itself and how it should adapt to its changing environment. I felt that this aspect of the paper was perhaps unfairly neglected. We have already seen traditional computer systems take over much of the routine work of the actuarial recruit of 20 years ago, and the changes compared with the work of 50 years ago are even more dramatic. The problem is most acute in the first months of a new recruit's career. Increased use of university courses designed to take the student quickly through the early stages of his professional exams will help, as would any reduction in the high numbers of students who never seem to make any significant progress in the exams at all. Our syllabus will need to keep pace with a changing environment. Mr Barnard reminded us that, as more and more is done by the computer, the reasons underlying the formulae and methods used must be understood by at least one actuary in an office. If the rôle of the senior actuary as a business man and strategist has not changed neither has the need for actuaries to meet the highest professional standards. The tools at the actuary's disposal have changed and are likely to continue to do so. He can ask for volumes of figures which could never have been produced for his predecessors, although the need for him to cross-check his data and to test it for reasonableness has not changed. Model offices and embedded value techniques are new tools which are becoming widely available and new actuarial theories which make use of the power of computers are already being developed, but the necessity of interpreting the data remains. Increasing numbers of projections sometimes only serve to remind us of the truth of the concept of the 'expanding funnel of doubt' put forward by Redington 35 years ago.

The concensus of the Working Party's report has been that developments in computer technology are likely to give us faster processing time and better communication. There will undoubtedly be changes in the way actuaries work and in the range of calculations available to them, and we know that we must be responsive. We have not identified any developments which are as great as the transition from the card-based systems of 20 years ago or the realization some 50 years ago of the possibilities inherent in binary methods of calculation. I hope that the next generation of actuaries will agree, with the benefit of hindsight, that we interpreted the situation correctly today, and that they will not subsequently view this debate as an opportunity missed.

The President (Mr R. D. Corley): Until comparatively recently a major concern of the actuary was to find ways of amalgamating data to reduce the number of individual calculations. We became skilled at packaging and averaging numerical data so that a single multiplication could take the place of hundreds, and we developed sophisticated techniques for checking the results and for determining the likely margins of error. The advent of the high-speed electronic calculator made much of this work unnecessary and led to questions of whether our rôle would be diminished. In practice the importance of the work of the actuary has increased over the last twenty years and it is interesting to speculate how much this is a result of the increasing availability and power of computers. It is, of course, true that if we had today's workload but no computers the need for ever more ingenious mathematical techniques to reduce labour-intensive calculations would keep an army of actuaries employed, and it may be the release from this work that has encouraged us to develop our skills in other directions.

In this country the comparative lightness of regulation has placed a welcome requirement on actuaries to develop their judgement, and as a profession our particular expertise lies in assessing the value of a long-term benefit against cost, or postponement of profit. This ability to balance long-term against short-term has been the foundation of the actuaries' contribution to investment management and other judgemental rôles. It is therefore fortunate that in recent years, when the need for well-founded judgement has been greatly increased by fluctuating rates of inflation and changes in the social environment, the advent of the computer has saved the profession from being overwhelmed by a dramatic increase in the technical burden. In other countries, the computer has provided the same release from calculation, but where tighter regulations have traditionally limited the actuaries' freedom to apply judgement, there seems to have been little consequential widening of the actuary's rôle. In this context it will be interesting to see whether the burgeoning interest in financial management will ever leave the theoretical domain in those countries where the actuarial influence has so far been limited to technological and research work.

If computers have given actuaries freedom and power they have also given us responsibilities. In attempting to draw together in one paper the essence of these responsibilities, the authors have rendered a valuable service to the profession. As a Research Group they have also produced a paper which is interesting in both its retrospective and prospective surveys. Some of the challenges in its closing chapters will continue to be debated around the profession long after this evening's meeting.

I would now like to propose a vote of thanks to the authors, and I would ask you to show your appreciation of the work done by the Research Group in preparing the paper.

Mr C. G. Lewin (replying): I would like to pick out one point which struck me as the most intriguing of all: that computers may actually be able to help us change the way we think, that they may become a really useful aid to the way we think and may even enable us to modify our personal thought processes. That is a longer term possibility, rather than a 5-year one, but the implications are mind-boggling.

I would like to endorse the suggestion that the Institute consider setting up a special standing committee (or asking the Futures Committee to take it on), to keep abreast of developments in the future: for helping us to channel our requirements to manufacturers, and for helping the profession to get to know about what is going on.

WRITTEN CONTRIBUTION

The authors subsequently wrote: We hope that our paper may prove to be the catalyst for action which will enable actuaries to keep ahead of the game in this field.

We were pleased to find that several speakers agreed with our view that there is room for the Institute to take a more active role. We still feel that this should not only consist of promulgating information to actuaries about what is likely to become available, but also informing the computer industry about the facilities which actuaries would find useful—in other words, a two-way process.

We reaffirm our view that the security of our computer systems is of crucial importance. They must be protected as far as possible from fraud or malicious damage. Even if every reasonable precaution is taken, there will always remain a small possibility of large financial losses occurring before a problem is uncovered. We disagree with Professor Needham's view that we are placing too much emphasis on this point.

We were interested in Mr Hey's comments about historical calculating machines. We, too, think the Millionaire machine was interesting, for the reason he states. He has also drawn our attention to the omission of the Mallock machine from our narrative of developments in the nineteen-thirties. It certainly deserved a mention. The mathematical analysis of structural frameworks (bridges, roof trusses, etc.) leads to sets of simultaneous linear equations with several unknowns. The need to solve these equations to a sufficient degree of accuracy is a practical problem that concerns engineers, and the Mallock machine was developed with that problem in mind. It was an analogue machine: it replaced the original physical problem by another physical problem which, (1) had the same mathematical formulation but, (2) was physically easier to solve. In the case of the Mallock machine the constants of equations were represented by electrical resistances which could be easily varied, and the unknowns were represented by electrical currents which could be easily measured. The machine is described in: *Proceedings of the Royal Society* (1933) **140**, p. 457. Two photographs of the machine are in the Science Museum (Inventory number INV 1937-150). They are listed in the Science Museum Catalogue, *Calculating Machines and Instruments*, Serial number 529, under the heading Trigonometrical and Equation Solving Machines. The great developments of digital computers in the last 30 years have perhaps led us to neglect analogue machines designed to solve particular problems. They have the great advantage that when we are using them we can, both literally and figuratively, see what we are doing. And we can also see what effect a small change in our data will have on the result.

We were criticized for failing to go into much detail about the many ingenious approximations which were developed by past generations of actuaries to enable full use to be made of the calculating devices then available. We should like to pay tribute to the actuaries concerned, many of whose methods were brilliant in conception and of great practical use. To do them full justice would, however, require a further paper! We believe that there will be at least as great a need for approximation techniques in the future, in order to place 'order of magnitude' checks on results obtained by computer, and we support Professor Benjamin's comments. This is a serious problem and considerable effort will be needed to find appropriate solutions. No doubt some of these new methods will be as ingenious as those adopted in the past.

Several speakers thought that we did not say enough about the developments in the computer field during the 1970s. We accept that this was a period when many more actuaries became fully immersed in computers and a great deal of useful work was done. We see it, however, as being mainly a period of consolidation of previous advances.

There was some discussion about our remarks on the difficulties inherent in producing actuarial computer programs suitable for use by the profession as a whole. A generalized annuity value has perhaps 20 or more variables. We accept that it should be possible nowadays to construct a program in which 'default values' for these variables come up automatically on the screen and those values would only be varied if necessary for the particular task in hand. However, for some applications, e.g. life office valuations, where large numbers of annuity values are required, it still often proves impracticable to do this. This leads on to the general point that the computers presently in use are not yet so fast or so powerful that one can do any calculations one requires on them. We disagree here with Mr O'Keeffe. Users' demands often outstrip the ability of computer departments to meet them.

We feel, incidentally, that there are some dangers in network systems of microcomputers, where there may often be no single person in charge of the system as a whole. This could lead to wasteful duplication of effort and a failure to ensure that the limitations of the data in the system are properly understood by all users.

We accept Mr Stoye's point that it would not be satisfactory merely to publish the formula underlying mortality rates and that there is a need for some limited publication of specimen values for checking purposes. Mr Stoye also commented on the need for much more software to be written, if possibilities such as those outlined in the paper are to be achieved. We agree that this is a major task for the years ahead. Much thought and effort is needed to find ways of increasing software productivity and, of great importance, software accuracy. Compromises will have to be made between the needs of the user and the ability of the programmer, and systems analysts will have to find the appropriate balance in each case. In general we do not agree with Mr Stoye that actuarial programs should be made available to non-actuaries, as we think that these could be dangerous in untrained hands.

With regard to Mr Granville's comments, we would be strongly in favour of all children being taught to type, as this skill will probably be needed very widely in the years ahead, despite the advent of 'user friendly' computer programs which might be thought to remove the need for typing.

On the question of whether some of today's complex contracts would have come about in the absence of computers, we detected differences in views among those who spoke on this point. We adhere to our opinion that, despite user demand, some of these contracts would have been deemed impossibly complicated from an administrative viewpoint in the pre-computer days. Moreover, less complicated external requirements were placed on actuaries (and others) in those days, because of a recognition that simplicity was essential if such requirements were to be met at all. Unfortunately there seems nowadays to be a tendency to assume that 'the computer can cope', however complicated the requirements, and this is not necessarily the case in practice. Even where the computer can cope, it is often far from easy for those working in the field to understand complex requirements and to explain them to others. It is often intellectually easier for those imposing requirements to make them complex than to devise simple requirements that meet 90% of the need, yet we suggest strongly that simple requirements of this kind would not only make everyone's life much easier, but also probably be more effective in the long run.

It was suggested by Professor Larmouth that we failed to talk about the next five years, but only the longer term future. In fact some of the developments we discussed will probably come about within the next five years, and we felt that there was little we could say that would be generally useful in respect of that period.

The Post Magazine and Insurance Monitor for 22 November 1856 carried an article describing the arithmometer, which was then in widespread use in France, and predicting that it would soon be considered as indispensable and generally useful as clocks. It was, however, many years before such machines came into general use in this country, and even ninety years later some actuaries were still using slide rules. The pace of change is now much quicker, and we cannot afford to fall behind. If we were to do so, we would open the door for other professions to encroach upon work that is best done by actuaries. The discussion was constructive and encourages us to believe that the various issues will be grasped firmly in the coming years. Nevertheless, great efforts will continue to be needed by individual actuaries and some degree of co-ordination by the Institute might well be of considerable assistance.