It is essential for our future national prosperity in Britain that we should modernize this country, by spreading an understanding of the most advanced forms of technology as rapidly as we can and throughout the whole of our society. We must somehow induce industrial concerns to adopt these new techniques quickly and intelligently, and we must make sure that our universities, our technical colleges, and our schools are mobilized to produce the people with the background, the training, and the inclination which is necessary to bring this about. We must also see to it that the correct political decisions are taken to make it easier, not more difficult, to realize these aims.

A great many disciplines and techniques are necessary for the successful introduction of automation. A large plant would need to have a staff with an expert knowledge of, for example, operational research and linear programming. It would have to be closely involved in such highly specialized activities as information analysis, queueing theories, and other mathematical concepts. This need to recruit and encourage rather scarce and expensive experts may be one of the reasons why, so far, the amount of real automation in existence is very limited. I doubt if it is to be found at present in more than a hundred companies within the whole of Great Britain. Perhaps the most notable of them is the Spencer steelworks.

But it is not necessary to believe that we are within sight of full automation throughout the whole of our industry in order to appreciate the enormous leap forward in productivity that automation makes possible. Nevertheless it would be a serious mistake, in my opinion, to think in terms of pre-automation and post-automation eras. In the real world, changes do not take place in such a neat and tidy manner. Conditions vary greatly from place to place and from industry to industry. The degree of automation which is economic is extremely elastic. Wages, transportation costs, markets—all these play a very important part in deciding to introduce more or less automation.

Automation is really an umbrella term for a complex of related systems. It includes, for instance, data processing and the scanning of information with alarm systems. It includes computation for specific purposes, for accountancy, for switching of information, for all kinds of recording, for observing, recording, and controlling every conceivable kind of activity—industrial, commercial, governmental, and social.

The heart of most systems of automation is an electronic computer. This is a very complicated piece of mechanism and of momentous importance, but it is, in fact, based on extremely simple principles.
Its distinguishing quality is a speed beyond human imagination, a speed measured in nano-seconds. A nanosecond can best be visualized as the time it takes for light to travel one foot—a thousandth of a millionth part of a second. Once we conceive that complex arithmetical sums can be done at that speed, we begin to realize the immense value of this new tool. It is a machine designed to read a binary code in which only two symbols are used—zero and 1. All numbers can be made up of a combination of these two symbols, because, at a given moment of time, zero can be represented by there being no electrical charge, and one by a charge being present. We can detect and count the pulses passing a given point in the machine, and this allows us to accumulate information at very high speeds, in a form in which it can be read, transcribed, and used for calculations. Because of the high speed, we can afford to go through a large number of elementary and simple steps to arrive at a most complicated answer.

The means of retaining the answers we get, in what we call the computer’s ‘memories’, has now reached a point where we can accumulate information, extract whatever we require, integrate with other information, make calculations using both existing and new information, feed the answer back into store, where it can be kept until it is wanted again, and compare it with further information as and when this arises.

**Miniature Computers**

A great deal of the future of electronic computers lies in the reduction in size, in the miniaturization. Much of this has already taken place. We can now visualize, as a practical proposition, a computer, which has hitherto needed a large room to contain it, being reduced to the size of a packet of a hundred cigarettes. The significance of this is not merely that the size is smaller, but that the speed is increased in an unprecedented fashion, because the electrical pulses have shorter distances to travel. A higher speed in computers means that their complexity can increase very rapidly, too, and that they can more easily engage in activities in what we call ‘real-time’. That is to say, they can calculate at the actual speed of the events taking place.

These machines can be made to do many things intelligently and can do them better than human beings, but they themselves cannot think. Any idea of ‘thinking machines’ is nonsense. They can be taught to improve their own performance by examining what they have done. That is true. But I do not think that we should call this thinking, although we can certainly -produce machines which will learn more and more successfully- from their own experience and so keep on improving their future performance as time goes on. They can accumulate information and sort out their own reasons for success and failure.

But to compare such machines to human beings is to endow them with intuitive qualities and with values and with subconscious sources of information, and these specifically human attributes they simply do not possess. As I said in my first lecture, automated machines are only an extension of man’s own capacities and not a substitute for man himself.

Nevertheless, machines like this can be used to do intelligent work if they are controlled by intelligent human beings, who exploit the machines by programming
them to perform particular jobs really well. They can even be made to write their own programmes. But without the initial human master programmer they cannot even begin.

**Not Thinking Machines**

A great deal of nonsense about computers is talked by otherwise intelligent scientists and much confusion has arisen because of the need to use terms like thinking and deciding in describing what these man-designed and manmade machines do. But it is important to bear in mind that, in fact, they do not think or decide. They simply operate on the basis of a value which is put into the machine by the programmer. They can say what and when and how much, but unless initially the programmer gives them detailed instructions, they cannot operate at all.

One of the most terrifying uses of computers is for war games, the idea being that the military can safely and sensibly use computers to play at nuclear war. This is a substitute for the old game of playing at war on maps. If you lay down formal criteria for a win then, of course, this is a fair game, but no one knows what constitutes a win in a nuclear war, or if today a win for either side is even possible. Anyone who is foolish enough to believe that he has conquered the secrets of winning a nuclear war, because he has discovered the tricks of winning a battle on a computer, is a most dangerous man.

This is merely one of the threats and perversions that arise through the abuse and misunderstanding of the use of computers.

When, on the other hand, we aim at using computers for sensible and constructive purposes, it is evident that automation technology has completely transformed the means of collecting data, measuring it and processing it for all kinds of investigation and activity: But to exploit these possibilities new disciplines and new methods of organization are required. These are now being developed and taught and standard practices are evolving from them. Today, for instance, no manager, book-keeper, administrator, or accountant can hope to remain aloof from the technological changes which are taking place around him.

Technology has invaded their realms, and although they may dislike and fear this, they must, from now on, work out their procedures in terms of the new sophisticated equipment and techniques which are being developed continuously. Although there is a growing awareness of this, there still exists a vast area where the possibilities are barely understood, let alone explored.

**What can be measured can be controlled**

It was Lord Kelvin who produced the terse and accurate comment on scientific endeavour that what can be measured can be understood. This has its modern counterpart—which is almost the motto for the Age of Automation—that what can be measured and made quantitative can be more precisely controlled. Man is not very well adapted for sensing or measuring accurately or frequently, especially where more than one or two variables are involved. Both manual and clerical tasks are accordingly broken down in order to fit the human capacity to observe, scrutinize, and control.
The need for man to be a part of a machine-system, in order to measure and control a situation, has hitherto proved a considerable barrier to progress. Automated machines, on the other hand, are not subject to these limitations, and consequently schemes for organization and control can now be conceived in terms of the end-product, rather than of a number of intermediate goals. And these machines are not limited to fixed and predetermined control strategies. Their control action is being continuously modified, as new information is received; they are always adapting to fresh situations. New man-machine partnerships can now be worked out in the control of processes and operations which up to now have relied almost exclusively on unaided man himself as the control agent. This is on the way to being achieved in such different fields as air traffic control, clinical medicine, baking, and oil and chemical processing. In each case, careful preparation and operational research are essential to achieve a fruitful man-machine relationship, so that the machine is given only those parts of the task which it can do best and the integrity and importance of final human judgment and decision are preserved.

Yet we are only on the threshold of these momentous possibilities. But the new framework of ideas evolving round automation technology is going to demand a great deal of rethinking of established management methods. We shall need many more people trained in operational research and cybernetics, and there will have to be an awareness of at least the basic principles of these subjects by an even broader section of the community. From now on no institution where private or public capital is employed on any scale will be immune from technological change, and what has begun to overtake business practice in recent years is already beginning to enter such less likely areas as hospitals and farming. Machines can perform any form of calculation, any type of book-keeping or accounting procedures. It is merely a matter of arranging the tasks to suit the machine. Machines can also carry out sequences of production operations, integrated by inter-process handling equipment.

Even by themselves, the three areas I mention - calculation, management accounting, and mechanization, comprise a great deal of the industrial, scientific, and commercial activity of our society. Yet they by no means exhaust the ways in which automation can help. The food industry provides many interesting examples. The manufacture of ice-cream, for instance, is now controlled by automatic method throughout, from the supply and blending of the ingredients to the final freezing, and baking is beginning to move in the same direction. This is surely overdue: it is surprising, even to the layman, to find how little instrumentation there still is in most continuous and expensive baking ovens. The bakery relies for the operation of its heavy investments on an experienced oven-man, and he in his turn relies on a great deal of what one can best call skilful guess-work in bringing the oven to the right temperature for baking. His skill lies mainly in allowing for variables in the process and for weather conditions. With long experience and a sound instinct he often guesses remarkably well, but by measuring automatically temperature, gas flow, humidity, and heat radiation levels it should be possible to specify exactly the conditions to be maintained for a particular type and quality of bake. In this way we could design an automatically controlled oven of great versatility that could be switched from one product to another, maintaining in each case a constant and appropriate baking environment. This would allow the planned production of more uniform products with a saving of fuel and reduction of wastage.
A similar type of approach is applicable to a vast number of industrial processes, from brick-making to laundry-work, and from steel to cheese, to an extent that goes far beyond the capacity of man alone. And the problems to be faced in the future are going to demand even further extensions of man’s sensing and controlling capabilities. The operations of widely separated factories, for instance, can be co-ordinated and controlled by automation systems, just as in a modern steelworks a complex of unit processes can be made fully interdependent.

Automation is not confined to commerce and the manufacturing industries. In the case of medicine, the wisest and most experienced specialist will inevitably have less knowledge of a particular condition than the medical profession as a whole: To arrive at his diagnosis in the classical manner, a doctor has to review what he knows and weigh it against the probabilities as he sees them. In the not too distant future we can imagine him referring the symptoms to an electronic library. This will supply him rapidly with a list of diseases, and their characteristics, which are compatible with the symptoms. A medical automation experimental unit has already been set up at University College Hospital in London. Automation specialists and medical specialists are working together to develop methods of speeding up administration, diagnosis, and research. The computer in use by the unit can search and tabulate medical record libraries, carry out statistical analysis, and help plan radiation treatment.

In medicine, as in other fields, human judgment, however, must still remain the final arbiter. The instinct, skill, and experience of an outstanding man will still be invaluable in arriving at a correct answer, but the chances of an important possibility being overlooked will be much reduced. The usefulness of the computer could be extended to cover not only symptoms and diseases but also tests, allergies, and treatments. The information would be checked continuously by the mass of clinical experience fed into it. In the case of research into, say, cancer, there would be methods of correlating lines of investigation and their results throughout the world. This would provide ready access to data to which neither the practising doctor nor the individual research worker could possibly gain access without machine assistance.

Hospital services could also benefit. A fresh approach, built around the framework of automation of data related to patients could deal with admissions, treatments, pharmacology, dietetics, clinical laboratories, wards, administration and research departments, each of which uses some part of the patient’s data. Doctors’ and nurses’ time could be saved by using automation technology to collect, record, edit, and transmit the appropriate data between the various departments of hospitals. This requires the re-thinking of hospital methods and procedures in order to delegate to machines the things they can do best, and in this way to help solve the labour shortages in hospitals. Technology has a valuable part to play in increasing the efficiency of our Health Service and in giving us a more adequate return on the huge capital invested in it.

I hope it is clear, from the examples I have given, that automation is not merely a matter of ‘hardware’, of machines. In none of the cases I have mentioned could one simply buy an electronic computer and use it effectively. The successful application of automation demands a combination of the right equipment for the purpose—that is to say, hardware—and adequate thought and intelligence—software. A computer
system can be disastrous if the firm or institution which has invested in it lacks the outlook and the understanding to handle it.

A whole range of new possibilities is being opened up by the development of extremely small computers, using micro-circuitry developed for communication systems in confined spaces, such as in aircraft or missiles. The enormous reduction in size that has taken place during recent years can be illustrated, perhaps, by saying that, whereas the computer of 1950 needed a large room to contain it, the 1964 model is down to the dimensions of a suitcase, and by 1974 the normal computer will be no bigger than a packet of a hundred cigarettes. In civilian life this kind of computer clearly has great advantages. It is now possible to envisage personal computers small enough to be taken round in one’s car, or even in one’s pocket. They could be plugged into a national computer grid, to provide individual inquirers with almost unlimited information. The availability of very small general-purpose computers is changing radically what we might perhaps describe as our computer philosophy. We can see that it is now possible to build computers with something approaching the amazing flexibility of the human brain. The human brain has a capacity which vastly exceeds the requirements of any particular moment. Today most computers are so large and expensive that they are generally confined to places and situations where their capacity can be fully used. But in the course of the next few years new techniques will enable computers to be produced so small and so cheaply that they could be carried about with no more difficulty than transistor radios. This will permit computers to be used in what, today, would be called a grossly inefficient manner.

This is one of the premises on which the American project, Project Mac, is based. The United States is now spending £5,000,000 a year on the development of a general-purpose computer which will be so easy to programme and to communicate with, that its services could be made widely available as a kind of public utility. The aim of Project Mac is to work out time-sharing techniques to enable a vast number of people to use a single computer simultaneously; to write master programmes that will allow people to do their own sub-programming, and to communicate with the computer in simple English. They are also aiming at developing a library of programmes of general usefulness. Any one of these would be immediately available through its code name.

Perhaps the most far-reaching use of the new generation of computers will be in the retention and communication of information of all sorts within national, possibly world-wide, information systems. This will enable decisions to be taken by people at all levels on a much more informed basis. Weather conditions and weather forecasts may be held in the system to provide local computers with the information for controlling both domestic and industrial heating and cooling plant. Complete air and road traffic situations may be stored in such a way that computers within the vehicle may be instructed to control the car or the helicopter safely to its destination. Car drivers could be told immediately about traffic hold-ups and road works and given alternative routes where delays were likely to occur on the direct road.

Everyone could be given access to a national economic computer. In this could be stored a vast amount of up-to-date details which could allow the individual worker, or a firm, to obtain the facts necessary for solving a particular problem. I am imagining, for instance, that one might want to know what the world output of certain
commodities or raw materials was running at, or what the current rate of transportation loading was. A large number of commercial decisions are made every day, and it takes a long time before the result of all these interim decisions can be expressed in terms of profitability or Stock Exchange prices. By means of a personal computer service of the kind I have been describing, we could have a system whereby a business man would decide on informed economic grounds what action to take. There would probably have to be some statutory provision to compel him to feed his decision back into the computer to prevent it from being starved of facts. If this were done, the machine would constantly be primed with the latest information, not necessarily about each individual action but certainly about the cumulative effect of a large number of individual actions.

On the other hand, in many industrial and commercial applications we are moving steadily away from large, centralized computers towards much simpler decentralized units, systems of small, cheap, special-purpose units, rather like building bricks. These allow an engineer, familiar with his own industry and its technology, progressively to build up anything from a simple process controller to a system for the full automation of a complete works. By following this method we are able to turn away from the monster, expensive, all-embracing computer installation to a system of progressive automation. A start can be made with a very modest capital outlay, in the knowledge that any extension of the system is easily achieved on the firm basis of later experience. This new modular, building-brick, hierarchical system, known as Arch, provides maximum security in operation and allows individual managers to keep a personal interest in the processes under their control and, even more important, in the staff who are responsible to them.

Another possible development, which may sound a little fantastic at the moment, is the complete translating machine. We have already at our disposal means of converting human vocal sounds into numerical symbols. We also have some knowledge of how to convert numerical symbols into vocal sounds, so the time is not far away when the computer will be able to recognize the pattern of speech and to reproduce artificially a human voice. Once this stage is reached we shall be able to speak into a computer and get the sound translated into electronic symbols. These symbols would not necessarily repeat the sound in English. They could repeat it in any other foreign language with which the sounds could be made compatible. So that it is quite reasonable to conceive a personal miniaturized translating machine which you would carry in your pocket and which would allow you to talk to a Chinese in English and allow him to reply in Chinese. But you would hear his reply in English. There would be limitations no doubt for a long time to come in the kind of vocabulary available and its size, and there would probably be technical hitches of various kinds, until perfection was ultimately reached. We know the jokes like ‘out-of-sight, out-of-mind’ appearing as ‘invisible idiot’. But technically there is no apparent reason why such an interpreting machine should not in fact be constructed fairly soon, if we are prepared to spend enough money. This proviso applies to all developments within the field of automation: finance for research is never unlimited, and any government or commercial concern naturally gives priority to those projects which appear likely to produce the most directly profitable results in the shortest time. And the order of priorities may well differ considerably from one country to another.