THE MACHINE AGE

BY

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By this time the public is well aware that a new age of machines is upon us based on the computing machine, and not on the power machine. The tendency of these new machines is to replace human judgment on all levels but a fairly high one, rather than to replace human energy and power by machine energy and power. It is already clear that this new replacement will have a profound influence upon our lives, but it is not clear to the man of the street what this influence will be.

In order to understand this new age, it must be realized that the new machine ideas have a respectable intellectual history and ancestry. The computing machine is the automatic mechanized successor to that calculus of reason which Leibniz suggested, and which he did so much to make actual in the form of his new mathematical symbolism. Two hundred and fifty years is not a short lineage for any intellectual project, and least of all for one which seems so new and revolutionary.

To understand what a computing machine is, let us compare a paper scheme of mathematical computation, a Chinese swan-ban or abacus and a Marchand or Fridén decimal computing machine for office use, and an electronic computing machine. Of these, the abacus is actually the oldest, but is not too familiar to the average man in the modern West. Let us then begin with an ordinary paper schedule of computations. In this, we depend on certain memorized combinations of numbers and rules of procedure to enable us to carry out ~~our~~

~~actual~~ our actual operations on our numbers. The multiplication table and the rules of elementary arithmetic represent something which needs human intervention to be carried out on paper, but this human intervention follows certain inhumanly rigid and memorized laws.

In the abacus we carry out a human intervention of exactly the same sort as in combining numbers on paper, but in this case the numbers are represented by the positions of balls along a wire rather than by pen or pencil marks. The notation is just as arbitrary as in an ordinary pen or pencil computation, but the operations have a more mechanical appearance, in that they consist of the bodily motion of certain pieces of matter. Nevertheless, there is not the slightest logical difference between the abacus and the ordinary paper computation.

In the third stage, that of the desk computing machine, the same operations which occur in the abacus are made according to rules which are not memorized in all their details, but which are entrusted to the instrument, and carried out by its intervention. There is no replacement of true thought by the machine, since the level of thought of the elementary processes as we carry them out on paper is that of routine. The desk computing machine is neither more nor less than a mechanized abacus, in which our memory is replaced by certain internal interlockings of the machine.

Finally, the high-speed electronic computing machine differs from the desk machine only in the speed of its operations and the much higher complications of its interlockings. Thus an operation which previously took hours may be reduced to a matter of seconds. I repeat, there is no logical change, and the reasoning calculus which is ordinary arithmetic, has been replaced by a reasoning machine which we may call Eniac or Edvac or some other new and artifical name. Nevertheless, the entirely altered time-relations of operations mean that the processes used for specific computations are not carried over in their entirety, but are replaced by other processes of similar nature, better suited for the machine.

So much for the machine as a computor. In the higher branches of mathematics, the ordinary operations of arithmetic are replaced in part by "quantized" operations in the logical sense: that is by operations concerning all or some entities, as well as by some operations concerning particular operations. As Turing has shown, these operations can be carried out on a suitable machine, and the computing machine may be replaced by a machine for mathematical proof. In such a machine, any work which the mathematician may do in a routine manner, may be done faster and more accurately than we can encompass it, and there will be many instancds where this is a preferable way of working to our ordinary mathematical prodedures. Nevertheless, the combinations are so increased in number beyond the ordinary arithmetical combinations, that the advantages: a, of striking out in a direction which our experience has told us is promising; and b, of aiming only at the discovery of those theorems which have a certain aesthetic or other special interest for us, will often be so great, that in many cases the routine computor cannot compete with the intelligent mathematician.

To some extent this advantage of the human operator may be overcome in the future by giving the machine the possibility of learning shortcut approaches and by building into the machine something of the human appreciation of particular situations, whether the appreciation be aesthetic or otherwise. The main basis for this construction of learning machines is understood at present, but the techniques of its detailed development are new and largely unexplored; and it is not yet possible to state in an unambiguous way those cases where the advantages are with the human mathematician and those cases where the advantages are with the machine.

I here use the word aesthetic. In fact, mathematics is an art as well as a science, and in the career of a mathematician it is quite as important to have a good taste for the theorems one tries to prove as to have success in proving a haphazard lot of theorems. This aesthetic taste is not equivalent to the ability to find theorems which are applicable to certain practical engineering situations; but on the other hand, it is definitely not independent of such success. The problem is too deep and too complicated for me to discuss it further in a popular article like the present.

We have so far spoken of the computing machine as an analogue to the human nervous system rather than to the whole of the human organism. Machines much more closely analogous to the human organism are well understood, and are now on the verge of being built. They will control entire endustrial processes and will even make possible the factory substantially without employees. In these the ultra-rapid digital computing machines will be supplemented by pieces of apparatus which take the readings of gauges, of thermometers, or photo-electric cells, and translate them into the digital input of computing machines. The new assemblages will also contain effectors, by which the numerical output of the central machine will be converted into the rotation of shafts, or the admission of chemicals into a tank, or the heating of a boiler, or some other process of the kind. Furthermore, the actual performance of these effector organs as well as their desired performance will be read by suitable gauges and taken back into the machine as part of the information on which it works.

The general outline of the processes to be carried out will be determined by what computation engineers call taping, which will state and determine the sequence of the processes to be performed. The possibility of learning may be built in by allowing the taping to be reestablished in a new way by the performance of the machine and the external impulses coming into it, rather than having it determined by a closed and rigid set-up, to be imposed on the apparatus from the beginning.

The limitations of such a machine are simply those of an understanding of the objects to be attained, and of the potentialities of each stage of the processes by which they are to be attained, and of our power to make logically determinate combinations of those processes to achieve our ends. Roughly speaking, if we can do anything in a clear and intelligible way, we can do it by machine. What the economic limitations will be:--namely, how we may determine whether it is desirable to use the machine rather than human effectors, is something which we cannot state unambiguously until we have more experience. It is, however, quite clear that apart from the taping, which is the job for an intelligent man rather than for a deft man, the apparatus which we shall depend upon in the future machine age is largely repetitive, and will be capable of being manufactured by the methods of mass production.

The present elaborate and more or less experimental computing machines cost probably something of the order of hundreds of thousands of dollars. The factory control machines of the future will both be less elaborate and more standardized than it is possible for many of us to imagine. The central part of these machines will cost somewhere in the thousands or tens of thousands of dollars. Large as this may seem, it is trivial in comparison with the annual wage benefit of even the moderate factory, and it must be remembered that a considerable part of it is capital investment rather than annual expense.

A very important question which concerns the impact that the automatic machine age may be expected to have on the future of mankind, is the question of time. If the present cold war peters out into a cold peace, the time of the automatic machine age is rather difficult to determine. On the one hand, there is ample evidence that more than one big engineering firm is quite aware of what is happening, and is prepared to start investigations without further delay into the possibilities of the automatic machine age. On the other hand, the situation of automatic techniques is not unlike that in which aviation found itself at the time of the Wrights. Aviation then was definitely on the docket as part of the environment into which the child of the times would grow up, but it took a generation to leave the stick-and-string plans of the first world war and the stick-and-string financing of the early aviation companies, to arrive at the international aviation network of the present time. It will not be until more than one company has gone bankrupt two or three times, and that its physical assets are no longer mortgaged to its founders and early investors, that the technique of automatic machines may be expected to reach any final stage. We could easily consume twenty years in this, and shall probably consume at least ten.

However, if we find ourselves in a hot war, in which large infantry armies will be needed, we shall also find ourselves in an economic situation in which the labor supply source falls far short of the demand. Under these conditions, it might well be as essential for our military men to push research on automatic machinery both for military and for industrial purposes, as it was for them to push research on radar and on automatic fire control, when the fate of the world was at stake in the Battle of ~~England~~ Britain. Thus, the history of radar is as good a measure as any of what we are to expect of automatic machines. If we place crews as extensive as those which developed the radar, on the problem of the automatic factory, it is quite reasonable to expect the automatic factory to be a reality in from two to four years. At the end of a war involving this type of automatic machinery, both the know-how and much of the equipment necessary to automatize our whole industry will be at our disposal; and if the apparatus is made available to individual entrepreneurs after the fashion customary at the ends of our recent wars, we had better look out, for then the new industrial revolution will be neither slow nor mild.

These new machines have a great capacity for upsetting the present basis of industry, and of reducing the economic value of the routine factory employee to a point at which he is not worth hiring at any price. If we combine our machine-potentials of a factory with the valuation of human beings on which our present factory system is based, we are in for an industrial revolution of unmitigated cruelty. We must be willing to deal in facts rather than in fashionable ideologies if we wish to get through this period unharmed. Not even the brightest picture of an age in which man is the master, and in which we all have an excess of mechanical services will make up for the pains of transition, if we are not both humane and intelligent.

Finally the machines will do what we ask them to do and not what we ought to ask them to do. In the discussion of the relation between man and powerful agencies controlled by man, the gnomic wisdom of the folk tales has a value far beyond the books of our sociologists. There is general agreement among the sages of the peoples of the past more likely to use it stupidly than to use it intelligently

ages, that if we are granted power commensurate with our will, we are more likely to use it wrongly than to use it rightly. Jacks' terrible story of the "Monkey's Paw" is a modern example of this. The father wishes for money and gets it as a compensation for the death of his son in a factory accident, then wishes for the return of his son. The son comes back as a ghost, and the father wishes him gone. This is the outcome of his three wishes.

Moreover, if we move in the direction of making machines which learn and whose behaviour is modified by experience, we must face the fact that every degree of independence we give the machine is a degree of possible defiance of our wishes. The genii in the bottle will not willingly go back in the bottle, nor have we any reason to expect them to be well disposed to us. In short, it is only a humanity which is capable of awe, which will also be capable of controlling the new potentials which we are opening for ourselves. We can be humble and live a good life with the aid of the machines, or we can be arrogant and die.