Artificial Intelligence: A Frontier of Automation

By Arthur L. Samuel

Abstract: Artificial intelligence is neither a myth nor a threat to man. It relates to a serious attempt to develop machine methods for dealing with some of the perplexing problems that should, in all justice, be delegated to machines but which now seem to require the exercise of human intelligence. Two fundamentally different approaches to the problem are being explored, the one aimed at a complete understanding of the intellectual processes involved and the other aimed at duplicating the assumed specific behavior of the brain. The first approach concerns itself with such matters as search, pattern recognition, learning, planning, and induction; the second approach involves a study of the behavior of random nets. It is fair to conclude that artificial intelligence promises to reduce rather than to augment technological unemployment.

Arthur L. Samuel, A.B., B.S., M.S., D.Sc. (hon.), Yorktown, New York, is Director of Research Communications for the International Business Machines Corporation, where he has been concerned with research problems underlying the design, construction, and use of digital computers. He has taught at Massachusetts Institute of Technology and University of Illinois and has done research on electron tubes for Bell Telephone Laboratories. His recent personal research effort has been in the field of machine learning. He is the author of many technical papers and has received over fifty United States patents.

ARTIFICIAL intelligence is an apparently self-evident phrase which has come into common usage without having a well-defined and generally accepted meaning. Unfortunately, this term also carries with it certain anthropomorphical implications which tend to arouse emotional responses on the part of the reader that have little or no bearing on the actual state of affairs. To some people, the concept of artificial intelligence is a scientific aberration defined as the Myth of Thinking Machines; to others, it relates to man's first stumbling attempts to develop machine methods for dealing with some of the perplexing problems that should, in all justice, be delegated to machines but which now seem to require the exercise of human intelligence; and, finally, to some easily frightened individuals, artificial intelligence refers to the impending danger of man's domination by the Machine. This divergence of opinion and of feelings, with respect to a subject that should be capable of scientific evaluation, bespeaks of a general lack of knowledge, which this discussion will attempt to correct.

As a matter of fact, a revolution is in the making with respect to the manner in which digital computers will be used to solve the problems of business and industry. This revolution has its beginnings in a variety of apparently unrelated research studies. Some of these studies seem to be directed toward quite uneconomic ends, such as programing * computers to match pennies, play tic-tac-toe, play checkers and chess, write poetry, compose music, and solve high school problems in plane geometry. Other studies are concerned with more practical problems—programing computers to read hand-sent telegraph signals, to recognize handwriting and speech, and to translate from Russian into English. Still others are concerned with learning machines, the mechanization of cognitive processes—yes, even with thinking machines. Some idea of the magnitude of the effort on these topics may be gained from the fact that a recently published bibliography [1] to the literature on artificial intelligence contained 559 references to individual papers by some 400 different authors and 26 additional references to symposia, proceedings, and other special collections concerning artificial intelligence, and this tabulation did not include mechanical translation, for which an earlier bibliography—1959—listed 645 papers. A large and growing body of workers, largely in the United States but with many members scattered throughout the civilized world, is attempting to write programs for existing machines or to design and build special machines all for the expressed purpose of performing tasks which, if done by human beings or by animals, would be described as involving some use of the intelligence. Regardless of our personal feelings as to the moral consequences of this form of automation, we cannot afford to ignore the revolutionary effect on our society which it portends.

ON THE FRINGE

As always, with any revolution, there is a lunatic fringe—people who believe in magic, or those who are carried away with their enthusiasm for a new cause and who make wild claims which tend to discredit the entire undertaking. The

* Ed. note: Mr. Samuel has called attention to the fact that the spelling of the words "programing," and "programed" is now done with two *m*'s by everybody in the computing industry. Because we are following the spelling in *Webster's*, we apologize to the author for not adopting the practice.

[1] Marvin Minsky, "A Selected Bibliography to the Literature on Artificial Intelligence," *IRE Transactions on Human Factors in Electronics*, Vol. 2 (March 1961), pp. 39–55.

field of artificial intelligence has, perhaps, had more than its share of these people. Norbert Wiener, who certainly does not belong in this category, has, nevertheless, fostered some of the loose thinking by maintaining, as a basic tenet of cybernetics, that a rather complete analogy exists between control functions in men and in machines and by insisting that machines can possess originality and that they are a threat to mankind.[2] In a contrary vein, Mortimer Taube[3] of Columbia University discounts the entire field of activity and, in effect, charges the workers in the field with "writing science fiction to titillate the public and to make an easy dollar or a synthetic reputation." Can we cut through a morass of detail and this mishmash of conflicting claims and, somehow or other, identify the true nature of artificial intelligence and of the revolution which is upon us?

To simplify our task, we will have to be quite arbitrary and exclude certain usages of digital computers such, for example, as calculating the stresses in an airplane wing, or computing a payroll, even though these usages do reduce the amount of human thinking which must be done. In a sense, the human thinking in these situations is done in advance by the people who write the set of instructions—the "program," in computer jargon—which spell out the series of individual steps that are to be taken in the computational process.

[2] Norbert Wiener, *Cybernetics; or, Control and Communication in the Animal and the Machine* (New York: John Wiley & Sons, 1948) and "Some Moral and Technical Consequences of Automation," *Science,* Vol. 131 (May 1960), p. 1355. See also Arthur L. Samuel, "Some Moral and Technical Consequences of Automation—A Refutation," *Science,* Vol. 132 (September 1960), p. 741.

[3] Mortimer Taube, *Computers and Common Sense—The Myth of Thinking Machines* (New York: Columbia University Press, 1961).

RUN-OF-THE-MILL COMPUTING

Since even these commonplace uses may seem a bit mysterious to the uninitiated, we might pause for a moment and point out that a digital computer is, after all, only an inanimate assemblage of mechanical and electrical parts that functions in a completely mechanistic fashion. As Lady Lovelace remarked over a hundred years ago in describing Charles Babbage's Analytic Engine, nothing comes out of the computer which has not been put into it, barring, of course, an infrequent case of malfunctioning, and the computer can only do what we know how to instruct it to do.

The magic of the computer resides not in what it can do but only in the speed and accuracy with which it performs a sequence of very simple computational steps, a sequence which, as we have said, has been specified in advance by the person who wrote the program and which derives its complexity and its utility from the involved relationships existing between the individual steps. Let us characterize these commonplace uses of digital computers by the fact that the answers which the computer is called upon to produce are all derived from the input data by the application of a strict set of rules that are known and that have been written down in advance by the programmer. These rules may be strictly logical, as in scientific problems, or as illogical as our income-tax laws, but they are definite and woe be it to him who violates them. In a sense, we may say that the answers are all contained in the input data and that the computer's function is that of rearranging the input data in a more convenient form by the application of certain rules.

Programing a computer for such computations is, at best, a difficult task, not primarily because of any inherent complexity in the computer itself but, rather, because of the need to spell out every minute step of the process in the most exasperating detail. Computers, as any programmer will tell you, are giant morons, not giant brains. By way of contrast, when one assigns a computational task to a human assistant, one tells the assistant what to do; when one writes a computer program, he must, in effect, tell the computer how to do the problem. This distinction between how and what is far from trivial. It distinguishes the poor employee from the good one, and, to a much greater extent, it differentiates between the digital computer, as a very efficient but extremely dumb computing aid, and an intelligent human being.

While the digital computer is a device for manipulating symbols of any kind, its genesis, as Allen Newell of Carnegie Institute of Technology has so aptly pointed out, lay in the desk calculator and in the business machine. Just as Babbage had earlier proposed, several innovations have been made to increase the usefulness of the device. In particular, three special types of units have been introduced in addition to the arithmetic unit. The first of these is the memory (more correctly, a storage unit) in which instructions and data can be retained until needed. Input and output devices are also added which enable the operator to introduce instructions and data into the machine and to obtain a record of the desired output. Finally, there is a central control unit which interprets the instructions one at a time and initiates three basic types of operations: moving information from one place to another, doing simple arithmetic, and transferring control to an instruction taken from one of two or more specified locations, depending upon a comparison that it makes between the signs or relative magnitude of specified numbers. These instructions are in the form of imperative statements, for example, move X to location A; add X to Y; skip an instruction if X is negative, and so on. The sequence of these statements which constitute the program is, as we have said, a specification as to how to do the problem rather than a statement as to what to do. Once this specification has been made, it is then only a matter of routine to use the computer to solve many of the problems of the workaday world.

As everyone knows, these commonplace uses of computers are of very great economic importance, so important, in fact, that they are already causing a revolution in our way of conducting research, of running mills, and of doing business. The important point to remember, however, is that these changes are brought about, not by some mystical process that can be known only to the elect few, but by the straightforward but detailed application of quite elementary procedures to problems that are essentially routine in nature.

ON THE FRONTIER

In contrast with these routine types of problems, there are many mental processes that people are called upon to perform that cannot be, or at least have not been, reduced to a simple set of rules. Take the process of playing a game of chess, not of simply adhering to the rules of the game, but rather the process of playing a good game against an intelligent opponent. There are no known procedures for guaranteeing a win, and yet people learn to play the game and some few become very proficient. Still another example might be the problem of proving theorems in plane geometry. Ignoring for a moment the Tarski decision procedure, which high school students do not know, it is still possible to develop a proficiency in proving theorems without involving the exhaustive process of writing down all possible strings of logically derived statements that might lead to a proof. Instead, one adopts a technique in which a number of more or less arbitrarily chosen procedures are explored in a rather incomplete fashion, each yielding some clue as to whether or not one is on the right track, until, through a series of hunches, one is led to a formulation of a satisfactory proof. In both of these cases, one can sometimes arrive at a correct or, at least, a very good answer in a remarkably short period of time, but there is a concomitant uncertainty as to whether or not a solution will ever be obtained and as to whether or not an apparent solution is the best solution.

Such a method of solving any problem has come to be known as a "heuristic" procedure, as contrasted with the use of an "algorithm," a term that is used in this connection to mean a completely specified solution procedure which can be guaranteed to give an answer if one but takes the time to follow through the specified steps. It should be noted that an attempted, but imperfect, algorithm is not per se an heuristic program. Heuristic problem-solving, when successful, must, obviously, be rated as a higher mental activity than the solving of problems by some more or less automatic procedure. We are, therefore, probably justified in attaching the label of artificial intelligence to machine methods and machine programs that make use of heuristic procedures.

There are two fundamentally different approaches to this problem of artificial intelligence. One approach, and this is the one that we will first discuss, consists in analyzing problems that seem to require the exercise of human intelligence and then devising a machine, or writing a program for an existing machine, which we hope will solve these problems. The specific mechanisms that the human brain employs in solving the problem do not here concern us; we analyze the problem, not the device that solves it. To call to mind a rather trite analogy, when man first attempted to fly, he studied the birds, and the early, unsuccessful flying machines were mechanical birds. It was not until man stopped studying birds and began to study aerodynamics that much progress was made. The modern jet airplane must cope with the same aerodynamical problems with which birds contend, but the mechanisms used in the solution of the problem of flight are quite different.

BIRD-WATCHING

The alternate approach—that of studying birds, not aerodynamics—does have its virtues, and, in the case of artificial intelligence where so much is still unknown, some very interesting results are being obtained by this route. I am referring to the general type of studies based on Donald Hebb's work at McGill, pioneered by Nathaniel Rochester of International Business Machines (IBM), by Farley and Clark of Massachusetts Institute of Technology, and, more recently, made popular by Frank Rosenblatt of Cornell University under the name of the Perceptron. The argument goes something like this. The brain of man, like that of the animals, is made up of many cells of a certain type called neurons. These cells have rather unusual properties; they react on an all-or-none basis ("fire" in the jargon of the trade) and transmit a pulse to other neurons through synaptic connections. Each neuron is connected to many others, and a number of input signals are, in general, required before a neuron will "fire." As far as we can determine, there is a certain amount of order in the over-all pattern of interconnections between the neurons, but there also appears to be a degree of randomness in the precise connections.

Learning seems to consist of alterations in the strength and even perhaps in the number of these synaptic interconnections. Now it is possible to devise a variety of mechanical, chemical, and electrical devices which simulate the behavior of individual neurons in a crude sort of way, and we can interconnect these devices in some random fashion to simulate the synaptic interconnections that exist within the brain, and, finally, we can arrange for the automatic strengthening or weakening of these interconnections using a training routine.

While the degree of intelligence achieved to date is indeed at a very low level, these devices have some very interesting properties. For one thing, they can be utilized in the solution of problems for which we do not have a complete mathematical formulation. A second and equally important attribute is that they are reasonably general purpose devices. As an example, a device built for the purpose of recognizing characteristic marks on paper might be trained to recognize English letters. The training would consist of presenting a sequence of inputs to the device, in this case the letters of the alphabet, and of strengthening those particular internal interconnections which would cause the device to give the correct response and of weakening connections leading to incorrect responses. This is quite analogous to the reward and punishment technique used in training animals. The important characteristic is that this device could equally well be trained to recognize Chinese or, for that matter to identify distinctive geographical features on an aerial survey map.

We will have time to mention only one additional characteristic, this being the apparent economy of elements, at least in terms of information storage, an economy which seems to result from the fact that the information is stored in the interconnections between the elements rather than in the elements themselves. We will return to this interesting subject after we have considered the "aerodynamics" of the problem.

BACK TO AERODYNAMICS

Marvin Minsky of Massachusetts Institute of Technology, in discussing the subject of artificial intelligence,[4] chose to divide the discussion into five different areas, these being Search, Pattern Recognition, Learning, Planning, and Induction. Although there is a degree of arbitrariness in this division, it seems to segment the problem in a way that enables one to come to grips with the essential features, and it demonstrates that there is no magic involved here. Instead, we are going to discuss a series of rather simple steps that can be mechanized. As an encapsulated summary, we can hardly do better than to quote Minsky:

> A computer can do, in a sense, only what it is told to do. But even when we do not know exactly how to solve a certain problem, we may program a machine to search through some large space of solution attempts. [That is, try many, many solutions, one after another.] Unfortunately, when we write a straightforward procedure for such a search we usually find the resulting process enormously inefficient. [There are just too many of them.] With Pattern Recognition techniques, efficiencies can be greatly improved by restricting the machine to use its methods only on the kind of attempts for which they are appropriate. And with Learning, efficiency is further improved by directing search in accord with earlier experience. By actually analyzing the situation, using what we call planning methods, the machine may obtain a really fundamental improvement by replacing the originally given Search by a much smaller, more appropriate exploration.

[4] Marvin Minsky, "Steps Towards Artificial Intelligence," *Proceedings of the I.R.E.*, Vol. 49 (January 1961), pp. 8–30.

Minsky concluded his summary by mentioning what he called some rather more global concepts relating to Induction, and it is perhaps here that we will go our separate ways.

To bring the discussion down to earth, let us consider what might be thought of as the more or less trivial problem of programing a computer to play checkers. I have chosen checkers rather than chess partly as a matter of personal bias (having written such a program myself [5]) and partly because of the apparent simplicity of the game which highlights the problem of search. To get a computer to play checkers we must, first of all, represent the pieces on the checkerboard in a fashion which can be stored in the computer. Then the consequences of each of the available moves are to be analyzed by looking ahead, much as a person might do, considering each initial move in turn, then all of the opponent's possible replies, and, for each of these, all of the counterreplies, and so on. The average person is only able to continue this look-ahead process for two or three moves in advance, but one might argue that, since computers are so very fast, it should be possible to search through all possible moves clear to the end of the game and so determine, unambiguously, the relative worth of the different possible first moves. Unfortunately, computers are not that fast. Projecting ahead to the fastest possible computer, subject only to such limitations as the size of the universe, the molecular nature of matter, and the finiteness of the speed of light, it would still take many centuries, perhaps more than the total age of the universe, for such a computer, using this procedure, to make its first move.

[5] Arthur L. Samuel, "Some Studies in Machine Learning Using the Game of Checkers," *IBM Journal of Research and Development*, Vol. 3, No. 3 (July 1959), p. 211.

HILL-CLIMBING

A person solves this problem by stopping the look-ahead process at a convenient point and by evaluating the resulting board position in terms of some intermediate goals: has he been able to capture one of his opponent's pieces without losing one in turn? has he been able to "king" a man? or, even, has he been able to develop an opening which will lead to the king row? This analysis cannot, by the nature of things, be exhaustive, and these secondary goals are not foolproof as indications that one is proceeding in the right direction. This general procedure is known as hill-climbing, and its shortcomings can be seen if one attempts to use it to get to the top of Mount Everest by always going uphill, starting, say, at Garden City, Long Island. There are two difficulties, the first being the existence of local peaks (if West Hill at 380 feet above sea level justifies such an appellation) and the second being the existence of flat regions subject to local perturbations (the surface of the ocean, for example) in which aimless meandering will occur unless very large steps are taken and the attendant danger that the desired peak may be completely missed unless the steps are small. Needless to say, a variety of different techniques have been developed to cope with these problems, but they may always be present to some degree, just as they always seem to plague man.

Having terminated a particular hill-climbing excursion, or a particular look-ahead process in the game of checkers, we must then determine the elevation, or evaluate the board position, to see if we are any nearer our goal. In the case of physical hill-climbing, there exist such things as altimeters with which we can measure our precise elevation, but, in the checker analogy, there is no simple measure of the goodness of a checker position. Of course, there is the possibility that we have encountered precisely the same position in some previous game, but this is highly unlikely except, perhaps, for opening positions and for the end game, so, instead, we must categorize the board situation, or classify it as belonging to some general class of board situations. The problem is not unlike that of recognizing a pattern of ink spots or smudges on the printed page which we identify as a printed character, an *A*, for example. This is the problem of pattern recognition.

Two steps are involved in pattern recognition. The first is the creation of a number of concepts, for example, roundness used in identifying *O*'s, straightness and the directionality of lines, and similar concepts. The second step is the assignment of weights to these various properties as they are used in identifying or classifying unknown characters. Attempts have been made to mechanize both of these steps, but, to date, very little progress has been made with respect to the concept-formation step, and most of the workers have been content to supply man-generated concepts and to develop machine procedures for assigning weights to these concepts.

MACHINE-LEARNING

It is here that we encounter the idea of machine learning. Suppose we arrange for some automatic means of testing the effectiveness of any current weight assignment in terms of actual performance and provide a mechanism for altering the weight assignment so as to maximize the performance. We need not go into the details of such a procedure to see that it could be made entirely automatic and to see that a machine so programed would "learn" from its experience. As a bit of corroborative evidence, the checker-playing program (to which I have alluded) does have this feature, and it is fairly easy to demonstrate that this program "learns" from its playing experience and that it gets to be a better and better checker player with time. An amusing consequence of this characteristic is that the program soon becomes able to beat the man who wrote the program, not because it makes use of any information or techniques not known or knowable to the man, but only because of its infallible memory, fantastic accuracy, and prodigious speed which enables it to make a detailed, but quite unimaginative, analysis in a few seconds which would take years for the man to duplicate.

We have gone into all of this detail not to make professional programmers out of our readers but, rather, to demonstrate how very prosaic the entire matter really is and how very far away from approximating the behavior of an intelligent human being our intelligent machines seem to be. I need only remind you that a checker master can still beat the best checker program, in spite of his pitiful memory by machine standards and a difference of more than one million in relative calculating speeds. Learning procedures have yet to be applied to anything more complicated than checkers, and the real problems to which we would like to address ourselves are many orders of magnitude more complicated.

A PARADOX

Perhaps we have said enough on the negative side. Progress is being made in machine learning, and we will someday understand why it is that a man can outperform a machine, and, as a result of this understanding, we will be able to devise better machines or even to program existing ones so that they can outperform man in most forms of mental activity. In fact, one suspects that our present machines would be able to do this now were we but smart enough to write the right kind of programs. The limitations are not in the machine but in man.

Here, then, is a paradox. In order to make machines which appear to be smarter than man, man himself must be smarter than the machine. A higher order of intelligence, or at least of understanding, seems to be required to instruct a machine in the art of being intelligent than is required to duplicate the intelligence which the machine is to simulate.

When we have at last achieved that degree of understanding required to write a program which will ape people in most of their mental activities, we will then feel the need to write a more generalized program for a machine which will cause it to write its own programs or to write programs for another machine. This, in turn, will require still greater understanding on the part of man. There is no end to this process, but, apparently, man as the originator will always be on top.

Our point, then, is that we have nothing to fear from the machine, at least in so far as there is any danger of the machine becoming more intelligent than man. The machine's intelligence is prescribed by man, and a higher intelligence is demanded for the prescription than for the execution.

ON SECOND THOUGHT

But, there is a fallacy in our argument. We have been assuming that man will not be able to construct an intelligent machine until he thoroughly understands the inner workings of such a device. Nevertheless, throughout history, man has discovered many properties of nature which he has not understood, and he has proceeded to use these properties both for good and for evil in spite of his lack of comprehension. We must, therefore, reckon with the possibility that man may yet create a Frankenstein monster in the form of an intelligent machine more or less by accident and long before he has developed the detailed knowledge required to control his own creation.

This brings us back to the alternate approach to the artificial-intelligence problem which we mentioned earlier, that of studying birds, not aerodynamics, since it seems reasonable to assume that, of the two alternatives, this approach is the more likely to lead to discovery without understanding. It will be recalled that the procedure is to simulate the brain by means of a randomly connected net of neuronlike devices in the hope that such an assemblage will possess intelligence. We might further argue that, since the details of the interconnections between the elements would be unknown, there would be a degree of uncertainty in our knowledge of the capabilities of the ensemble and in our ability to predict its behavior and, to this extent, the device might develop an intellect superior to that of man, its creator.

Such a development is, however, extremely unlikely. In the first place, there is the matter of relative size. It becomes increasingly difficult to interconnect neuronlike devices when the number gets much larger than, say, 10^6 or 10^7 elements, and, under these conditions, the individual devices must, of necessity, be quite simple. By way of contrast, the brain of man contains perhaps 10^{10} neurons, and the individual neurons have many processes which connect them in a very complicated way to other neurons. There are perhaps a hundred such connections on the average per neuron. In the face of this complexity, our feeble attempts at simulation resemble the nervous system of the flatworm more nearly than they duplicate the brain of man. This situation will not always prevail, and, with some of the newer computer-fabrication techniques, we may someday be able to make devices which approach the brain in complexity.

ONE CHANCE IN A MILLION-MILLION

A second factor has to do with our lack of knowledge concerning the detailed ordering of the interconnections in the brain. The brain certainly is not connected at random, although one can advance arguments to support the thesis that chance must play a part. For example, with a complexity measured by something like 10^{20}, it is hard to see how the entire specification can be contained in a germ plasm. There is also evidence of a great amount of redundancy, for there are cases in which relatively large portions of the brain have been damaged, or even removed, without any serious long-range impairment of the mental faculties.

Arguing on the other side, there is an observable gross ordering common to all brains. Above and beyond this, there is the ordering which is obviously necessary to provide the newborn child with the many reflexes and instinctive behavior patterns so necessary for his survival. Order is also betrayed by the many detailed mental quirks which we inherit. Finally, while men of genius, on the average, appear to have larger brains than their less fortunate brethren, this is certainly not universally the case, and the chief difference between prodigies and the mentally deficient seems to reside more in the detailed structuring of their brains than in mere bulk.

Of course, since we know substantially nothing about the ordering of the brain, an assumption of randomness is as good a place to start as anywhere else, but our chance of constructing a device resembling the brain of man is then something like one in 10^{12}. It will only be through an increased understanding of the basic mechanisms involved that we will be able to increase these odds, and, to the extent that we increase our understanding, we also increase our ability to control.

We can, therefore, reaffirm our previous conclusion that we have nothing to fear from the machine in terms of domination. This does not mean that man may not use the computer to harm mankind. The digital computer of today and the intelligent machine of the morrow are tools, just as the typewriter, the steam shovel, and the thermonuclear bomb are tools, and most, if not all, of man's tools may be employed by both saints and sinners. The digital computer may lack some of the destructive power of the bomb, but then the bomb owes much of its effectiveness to calculations made by computers and, in a sense, the computer will have to share the blame if man succeeds in destroying himself. It will be man, however, who must bear the ultimate responsibility, and attempts to assign blame to an inanimate collection of mechanical and electrical parts which man assembles, or causes to be assembled, constitute a shabby form of buck-passing.

MUSICAL CHAIRS

The entire threat of the intelligent machine is not so easily dismissed as one might judge from these remarks. While the machine may never be more intelligent than man, men vary in their intellectual capabilities, and the machine may and undoubtedly will surpass some men. The threat, then, is more one of technological unemployment than of domination. In a sense, this is but a continuation of the process which has been going on ever since man made his first invention. Such a statement does not solve the problem, but, in terms of its gross effect on employment, the intelligent machine should be looked on as just another form of automation and should not be singled out for especial approbation. Artificial intelligence is, of course, something more than another labor-saving device, since it augments man's brain rather than his brawn. In fact, it is quite apt to be that added factor in our economy which will enable man to solve the entire problem of technological unemployment, including that portion, if any, caused by its own introduction.

Programing computers to play games, to write poetry, and to solve high school problems is but one stage in the development of an understanding of the methods which must be employed for the machine simulation of intellectual behavior. We are still in the game-playing stage, but, as we progress in our understanding, it seems reasonable to assume that these newer techniques will be applied to real-life situations with increasing frequency and that the effort devoted to games and other toy problems will decrease. Perhaps we have not yet reached this turning point, and we may still have much to learn. Nevertheless, it seems certain that the time is not far distant when most of the more humdrum mental tasks, which now take so much human time, will be done by machine. Artificial intelligence is neither a myth nor a threat to man.