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CHESS MACHINE of the 18th century was actually run by man inside.

A Chess-Playing Machine

Electronic computers can be set up to play a fairly strong game, raising the question of whether they can "think"

by Claude E. Shannon

FOR CENTURIES philosophers and scientists have speculated about whether or not the human brain is essentially a machine. Could a machine be designed that would be capable of "thinking"? During the past decade several large-scale electronic computing machines have been constructed which are capable of something very close to the reasoning process. These new computers were designed primarily to carry out purely numerical calculations. They perform automatically a long sequence of additions, multiplications and other arithmetic operations at a rate of thousands per second. The basic design of these machines is so general and flexible, however, that they can be adapted to work symbolically with elements representing words, propositions or other conceptual entities.

One such possibility, which is already being investigated in several quarters, is that of translating from one language to another by means of a computer. The immediate goal is not a finished literary rendition, but only a word-by-word translation that would convey enough of the meaning to be understandable. Computing machines could also be employed for many other tasks of a semi-rote, semi-thinking character, such as designing electrical filters and relay circuits, helping to regulate airplane traffic at busy airports, and routing long-distance telephone calls most efficiently over a limited number of trunks.

Some of the possibilities in this direction can be illustrated by setting up a computer in such a way that it will play a fair game of chess. This problem, of course, is of no importance in itself, but it was undertaken with a serious purpose in mind. The investigation of the chess-playing problem is intended to develop techniques that can be used for more practical applications.

The chess machine is an ideal one to start with for several reasons. The problem is sharply defined, both in the allowed operations (the moves of chess) and in the ultimate goal (checkmate). It is neither so simple as to be trivial nor too difficult for satisfactory solution. And such a machine could be pitted against a human opponent, giving a clear measure of the machine's ability in this type of reasoning.

There is already a considerable literature on the subject of chess-playing machines. During the late 18th and early 19th centuries a Hungarian inventor named Wolfgang von Kempelen astounded Europe with a device known as the Maelzel Chess Automaton, which toured the Continent to large audiences. A number of papers purporting to explain its operation, including an analytical essay by Edgar Allan Poe, soon appeared. Most of the analysts concluded, quite correctly, that the automaton was operated by a human chess master concealed inside. Some years later the exact manner of operation was exposed (*see drawing at upper left*).

A more honest attempt to design a chess-playing machine was made in 1914 by a Spanish inventor named L. Torres y Quevedo, who constructed a device that played an end game of king and rook against king. The machine, playing the side with king and rook, would force checkmate in a few moves however its human opponent played. Since an explicit set of rules can be given for making satisfactory moves in such an end game, the problem is relatively simple, but the idea was quite advanced for that period.

AN electronic computer can be set up to play a complete game. In order to explain the actual setup of a chess machine, it may be best to start with a general picture of a computer and its operation.

A general-purpose electronic computer is an extremely complicated device containing several thousand vacuum tubes, relays and other elements. The basic principles involved, however, are quite simple. The machine has four main parts: 1) an "arithmetic organ," 2) a control element, 3) a numerical memory and 4) a program memory. (In some designs the two memory functions are carried out in the same physical apparatus.) The manner of operation is exactly analogous to a human computer carrying out a series of numerical calculations with an ordinary desk computing machine. The arithmetic organ corresponds to the desk computing machine, the control element to the human operator, the numerical memory to the work sheet on which intermediate and final results are recorded, and the program memory to the computing routine describing the series of operations to be performed.

In an electronic computing machine, the numerical memory consists of a large number of "boxes," each capable of holding a number. To set up a problem on the computer, it is necessary to assign box numbers to all numerical quantities involved, and then to construct a program telling the machine what arithmetical operations must be performed on the numbers and where the results should go. The program consists of a sequence of "orders," each describing an elementary calculation. For example, a typical order may read A 372, 451, 133. This means: add the number stored in box 372 to that in box 451, and put the sum in box 133. Another type of order requires the machine to make a decision. For example, the order C 291, 118, 345 tells the machine to compare the contents of boxes 291 and 118; if the number in box 291 is larger, the machine goes on to the next order in the program; if not, it takes its next order from box 345. This type of order enables the machine to choose from alternative procedures, depending on the results of previous calculations. The "vocabulary" of an electronic computer may include as many as 30 different types of orders.

After the machine is provided with a program, the initial numbers required for the calculation are placed in the numerical memory and the machine then automatically carries out the computation. Of course such a machine is most useful in problems involving an enormous number of individual calculations, which would be too laborious to carry out by hand.

THE problem of setting up a computer for playing chess can be divided into three parts: first, a code must be chosen so that chess positions and the chess pieces can be represented as numbers; second, a strategy must be found for choosing the moves to be made; and third, this strategy must be translated into a sequence of elementary computer orders, or a program.

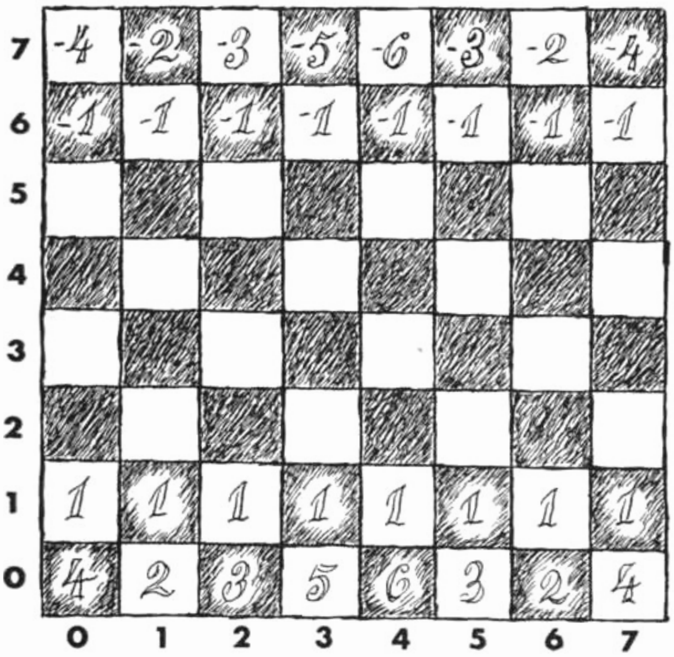
A suitable code for the chessboard and the chess pieces is shown in the diagram to the left at the bottom of this page. Each square on the board has a number consisting of two digits, the first digit corresponding to the "rank" or horizontal row, the second to the "file" or vertical row. Each different chess piece also is designated by a number: a pawn is numbered 1, a knight 2, a bishop 3, a rook 4 and so on. White pieces are represented by positive numbers and black pieces by negative ones. The positions of all the pieces on the board can be shown by a sequence of 64 numbers, with zeros to indicate the empty squares. Thus any chess position can be recorded as a series of numbers and stored in the numerical memory of a computing machine.

A chess move is specified by giving the number of the square on which the piece stands and of the one to which it is moved. Ordinarily two numbers would be sufficient to describe a move, but to take care of the special case of the promotion of a pawn to a higher piece a third number is necessary. This number indicates the piece to which the pawn is converted. In all other moves the third number is zero. Thus a knight move from square 01 to 22 is encoded into 01, 22, 0. The move of a pawn from 62 to 72, and its promotion to a queen, is represented by 62, 72, 5.

The second main problem is that of deciding on a strategy of play. A straightforward process must be found for calculating a reasonably good move for any given chess position. This is the most difficult part of the problem. The program designer can employ here the principles of correct play that have been evolved by expert chess players. These empirical principles are a means of bringing some order to the maze of possible variations of a chess game. Even the high speeds available in electronic computers are hopelessly inadequate to play perfect chess by calculating all possible variations to the end of the game. In a typical chess position there will be about 32 possible moves with 32 possible replies—already this creates 1,024 possibilities. Most chess games last 40 moves or more for each side. So the total number of possible variations in an average game is about 10^{120}. A machine calculating one variation each millionth of a second would require over 10^{95} years to decide on its first move!

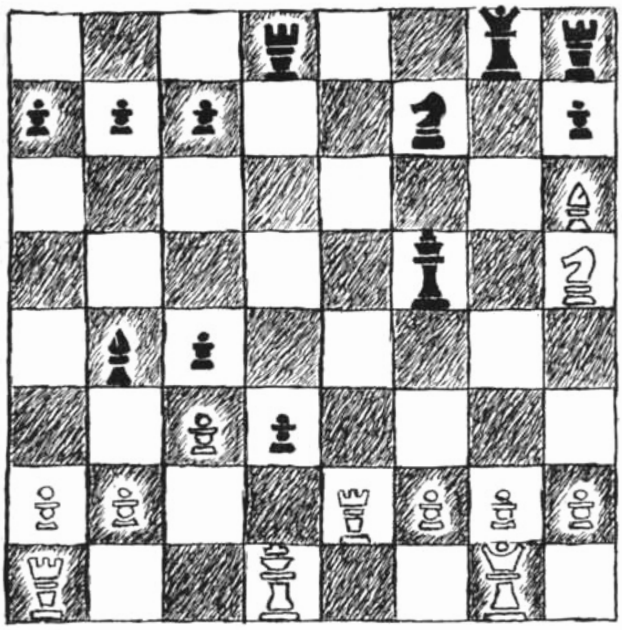
Other methods of attempting to play perfect chess seem equally impracticable; we resign ourselves, therefore, to having the machine play a reasonably skillful game, admitting occasional moves that may not be the best. This, of course, is precisely what human players do: no one plays a perfect game.

In setting up a strategy on the machine one must establish a method of numerical evaluation for any given chess position. A chess player looking at a position can form an estimate as to which side, White or Black, has the advantage. Furthermore, his evaluation is roughly quantitative. He may say, "White has a rook for a bishop, an advantage of about two pawns"; or "Black has sufficient mo-



	0	1	2	3	4	5	6	7
7	-4	-2	-3	-5	-6	-3	-2	-4
6	-1	-1	-1	-1	-1	-1	-1	-1
5								
4								
3								
2								
1	1	1	1	1	1	1	1	1
0	4	2	3	5	6	3	2	4

CODE for a chess-playing machine is plotted on a chessboard. Each square can be designated by two digits, one representing the horizontal row and the other the vertical. Pieces also are coded in numbers (*see text*).



PROBLEM that the machine could solve brilliantly might begin with this chess position. The machine would sacrifice a rook and a queen, the most powerful piece on the board, and then win in only one more move.

bility to compensate for a sacrificed pawn." These judgments are based on long experience and are summarized in the principles of chess expounded in chess literature. For example, it has been found that a queen is worth nine pawns, a rook is worth five, and a bishop or a knight is worth about three. As a first rough approximation, a position can be evaluated by merely adding up the total forces for each side, measured in terms of the pawn unit. There are, however, numerous other features which must be taken into account: the mobility and placement of pieces, the weakness of king protection, the nature of the pawn formation, and so on. These too can be given numerical weights and combined in the evaluation, and it is here that the knowledge and experience of chess masters must be enlisted.

ASSUMING that a suitable method of position evaluation has been decided upon, how should a move be selected? The simplest process is to consider all the possible moves in the given position and choose the one that gives the best immediate evaluation. Since, however, chess players generally look more than one move ahead, one must take account of the opponent's various possible responses to each projected move. Assuming that the opponent's reply will be the one giving the best evaluation from his point of view, we would choose the move that would leave us as well off as possible after his best reply. Unfortunately, with the computer speeds at present available, the machine could not explore all the possibilities for more than two moves ahead for each side, so a strategy of this type would play a poor game by human standards. Good chess players frequently play combinations four or five moves deep, and occasionally world champions have seen as many as 20 moves ahead. This is possible only because the variations they consider are highly selected. They do not investigate all lines of play, but only the important ones.

The amount of selection exercised by chess masters in examining possible variations has been studied experimentally by the Dutch chess master and psychologist A. D. De Groot. He showed various typical positions to chess masters and asked them to decide on the best move, describing aloud their analyses of the positions as they thought them through. By this procedure the number and depth of the variations examined could be determined. In one typical case a chess master examined 16 variations, ranging in depth from one Black move to five Black and four White moves. The total number of positions considered was 44.

Clearly it would be highly desirable to improve the strategy for the machine by including such a selection process in it. Of course one could go too far in this direction. Investigating one particular line of play for 40 moves would be as bad as investigating all lines for just two moves. A suitable compromise would be to examine only the important possible variations—that is, forcing moves, captures and main threats—and carry out the investigation of the possible moves far enough to make the consequences of each fairly clear. It is possible to set up some rough criteria for selecting important variations, not as efficiently as a chess master, but sufficiently well to reduce the number of variations appreciably and thereby permit a deeper investigation of the moves actually considered.

The final problem is that of reducing the strategy to a sequence of orders, translated into the machine's language. This is a relatively straightforward but tedious process, and we shall only indicate some of the general features. The complete program is made up of nine sub-programs and a master program that calls the sub-programs into operation as needed. Six of the sub-programs deal with the movements of the various kinds of pieces. In effect they tell the machine the allowed moves for these pieces. Another sub-program enables the machine to make a move "mentally" without actually carrying it out: that is, with a given position stored in its memory it can construct the position that would result if the move were made. The seventh sub-program enables the computer to make a list of all possible moves in a given position, and the last sub-program evaluates any given position. The master program correlates and supervises the application of the sub-programs. It starts the seventh sub-program making a list of possible moves, which in turn calls in previous sub-programs to determine where the various pieces could move. The master program then evaluates the resulting positions by means of the eighth sub-program and compares the results according to the process described above. After comparison of all the investigated variations, the one that gives the best evaluation according to the machine's calculations is selected. This move is translated into standard chess notation and typed out by the machine.

It is believed that an electronic computer programmed in this manner would play a fairly strong game at speeds comparable to human speeds. A machine has several obvious advantages over a human player: 1) it can make individual calculations with much greater speed; 2) its play is free of errors other than those due to deficiencies of the program, whereas human players often make very simple and obvious blunders; 3) it is free from laziness, or the temptation to make an instinctive move without proper analysis of the position; 4) it is free from "nerves," so it will make no blunders due to overconfidence or defeatism. Against these advantages, however, must be weighed the flexibility, imagination and learning capacity of the human mind.

Under some circumstances the machine might well defeat the program designer. In one sense, the designer can surely outplay his machine; knowing the strategy used by the machine, he can apply the same tactics at a deeper level. But he would require several weeks to calculate a move, while the machine uses only a few minutes. On an equal time basis, the speed, patience and deadly accuracy of the machine would be telling against human fallibility. Sufficiently nettled, however, the designer could easily weaken the playing skill of the machine by changing the program in such a way as to reduce the depth of investigation (*see drawing on opposite page*). This idea was expressed by a cartoon in *The Saturday Evening Post* a while ago.

AS described so far, the machine would always make the same move in the same position. If the opponent made the same moves, this would always lead to the same game. Once the opponent won a game, he could win every time thereafter by playing the same strategy, taking advantage of some particular position in which the machine chooses a weak move. One way to vary the machine's play would be to introduce a statistical element. Whenever it was confronted with two or more possible moves that were about equally good according to the machine's calculations, it would choose from them at random. Thus if it arrived at the same position a second time it might choose a different move.

Another place where statistical variation could be introduced is in the opening game. It would be desirable to have a number of standard openings, perhaps a few hundred, stored in the memory of the machine. For the first few moves, until the opponent deviated from the standard responses or the machine reached the end of the stored sequence of moves, the machine would play by memory. This could hardly be considered cheating, since that is the way chess masters play the opening.

We may note that within its limits a machine of this type will play a brilliant game. It will readily make spectacular sacrifices of important pieces in order to gain a later advantage or to give checkmate, provided the completion of the combination occurs within its computing limits. For example, in the position illustrated at the lower right on page 49 the machine would quickly discover the sacrificial mate in three moves:

	White	*Black*
1.	R-K8 Ch	R X R
2.	Q-Kt4 Ch	Q X Q
3.	Kt-B6 Mate	

Winning combinations of this type are frequently overlooked in amateur play.

The chief weakness of the machine is

that it will not learn by its mistakes. The only way to improve its play is by improving the program. Some thought has been given to designing a program that would develop its own improvements in strategy with increasing experience in play. Although it appears to be theoretically possible, the methods thought of so far do not seem to be very practical. One possibility is to devise a program that would change the terms and coefficients involved in the evaluation function on the basis of the results of games the machine had already played. Small variations might be introduced in these terms, and the values would be selected to give the greatest percentage of wins.

THE GORDIAN question, more easily raised than answered, is: Does a chess-playing machine of this type "think"? The answer depends entirely on how we define thinking. Since there is no general agreement as to the precise connotation of this word, the question has no definite answer. From a behavioristic point of view, the machine acts as though it were thinking. It has always been considered that skillful chess play requires the reasoning faculty. If we regard thinking as a property of external actions rather than internal method the machine is surely thinking.

The thinking process is considered by some psychologists to be essentially characterized by the following steps: various possible solutions of a problem are tried out mentally or symbolically without actually being carried out physically; the best solution is selected by a mental evaluation of the results of these trials; and the solution found in this way is then acted upon. It will be seen that this is almost an exact description of how a chess-playing computer operates, provided we substitute "within the machine" for "mentally."

On the other hand, the machine does only what it has been told to do. It works by trial and error, but the trials are trials that the program designer ordered the machine to make, and the errors are called errors because the evaluation function gives these variations low ratings. The machine makes decisions, but the decisions were envisaged and provided for at the time of design. In short, the machine does not, in any real sense, go beyond what was built into it. The situation was nicely summarized by Torres y Quevedo, who, in connection with his end-game machine, remarked: "The limits within which thought is really necessary need to be better defined . . . the automaton can do many things that are popularly classed as thought."

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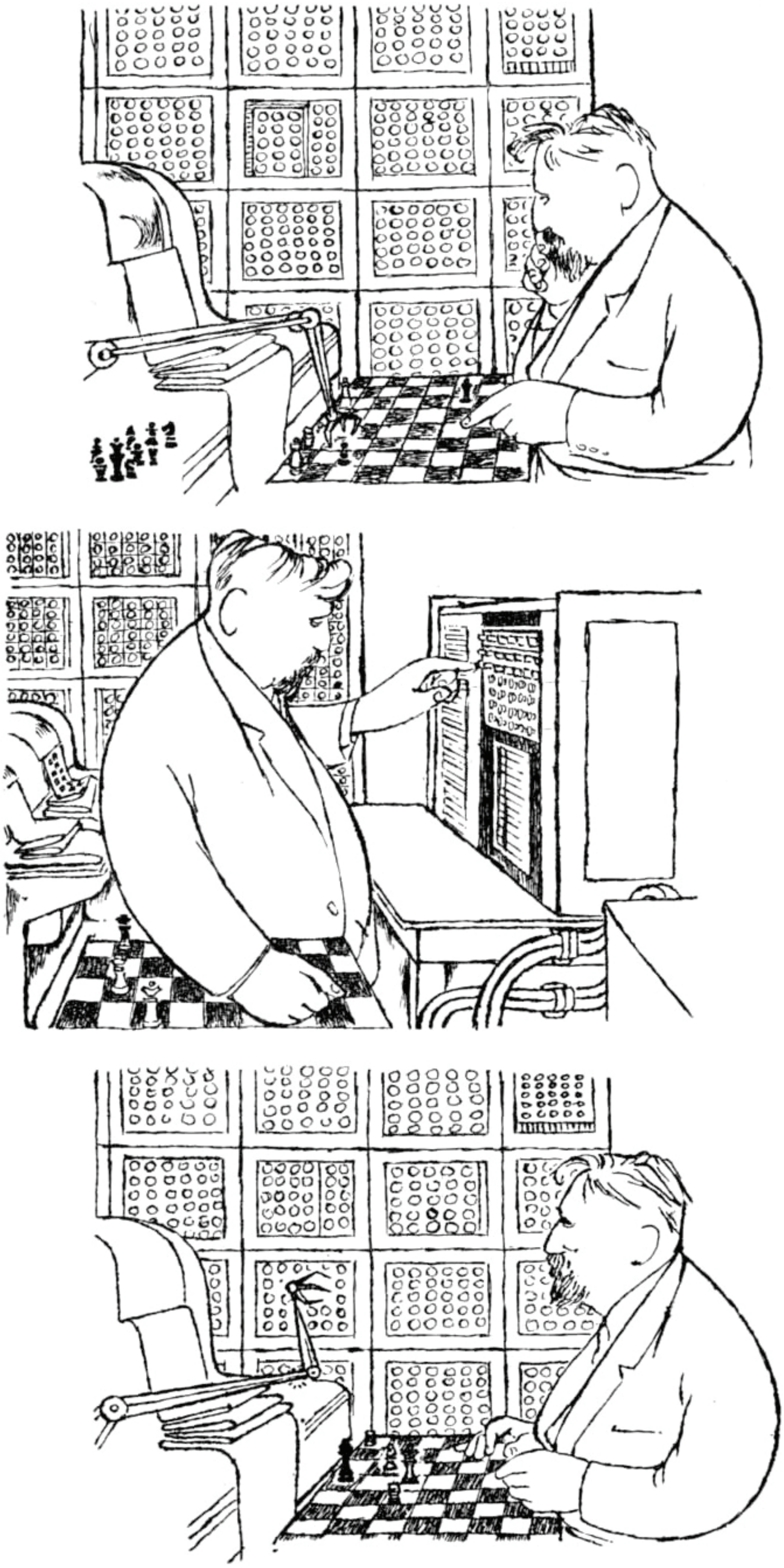

INEVITABLE ADVANTAGE of man over the machine is illustrated in this drawing. At top human player loses to machine. In center nettled human player revises machine's instructions. At bottom human player wins.