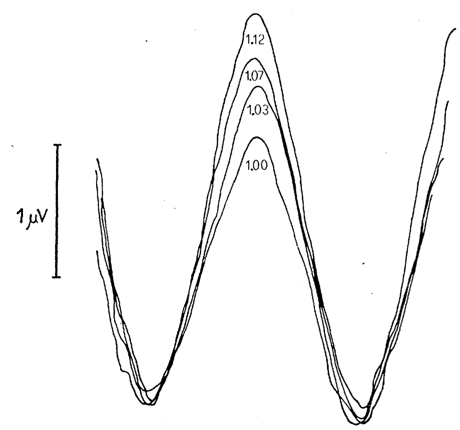

Fig. 2. Average evoked responses recorded as for Fig. 1. The stimulus patterns were two circular square-wave gratings 5.5 deg in diameter, which were binocularly superimposed. The spatial frequency of the right-eye grating was 1.33 cycle/deg. The spatial frequency of the left-eye grating had four different values. The ratios of the two frequencies are indicated in the figure. The contrast of the gratings was about 1.5 log units above threshold.

Gratings, consisting of vertical bars, were electronically generated on two equal oscilloscopes viewed stereoscopically by the subject, from a distance of 75 cm. The luminance varied along the horizontal direction either sinusoidally or as a square wave. This pattern was then shifted in phase through 180 deg at a temporal frequency of 8 cycle/sec. In this way the light flux entering the eye remained constant. Such a moving pattern evoked potentials that may be recorded from the occipital area of the scalp (Figs. 1 and 2).

When the spatial frequencies of the two gratings were equal, a single grating was perceived stereoscopically which appeared to lie in a frontal plane. If the spatial frequency of one grating was slightly different from the other, the fused binocular image appeared to be inclined, with the left side closer to the subject and the right side farther, or conversely, according to whether the grating seen by the left eye had the higher or the lower spatial frequency (*3*). The apparent inclination of the grating increases with the difference in frequency up to a maximum that for the conditions of our experiment occurred when one frequency was about 12 percent greater than the other.

The records presented in Figs. 1 and 2 are each the average of 1000 responses. The first set of evoked potentials (Fig. 1A) was obtained with two gratings, which were not superimposed, with equal (Fig. 1, A_1) or different (Fig. 1, A_2) spatial frequencies. The second set was obtained with two gratings which appeared binocularly superimposed, again with either equal (Fig. 1, B_1) or different (Fig. 1, B_2) spatial frequencies. The difference in spatial frequency was such that the grating perceived under the latter condition appeared with the greatest inclination.

The first set of responses (Fig. 1, A_1 and A_2) have approximately the same amplitude but are both considerably smaller than the responses of the second set (Fig. 1, B_1 and B_2). Furthermore, the response B_1, obtained with gratings of equal spatial frequency, is appreciably smaller than the response B_2 obtained with gratings of different spatial frequencies. The difference in amplitude between B_1 and B_2 has been repeatedly verified at different average spatial frequencies in 21 experiments. The average amplitude of B_2 is 1.3 times greater than that of B_1, with a standard deviation of 0.2.

The responses presented in Fig. 2 have been obtained with two binocularly superimposed gratings for a constant spatial frequency in one eye (1.33 cycle/deg) and various spatial frequencies in the other eye. The amplitude of the responses increases as the difference in frequency increases from 0 to 12 percent; this corresponds to the increasing apparent inclination of the binocular pattern. For differences in frequency above 25 percent, at which no tilt of the pattern is any longer perceived, the amplitude of the evoked potential seems to remain constant or to decrease.

Clearly, it is only when the visual neurons are stimulated binocularly that a difference in the spatial frequency of the two monocular patterns, such as to produce depth perception, brings about a consistent increase in the amplitude of the response. This fact is in agreement with the electrophysiological findings in the cat visual cortex, where most of the neurons that are binocularly driven present the highest firing frequency when the two monocular stimuli are disparate (*4*).

ADRIANA FIORENTINI
LAMBERTO MAFFEI
Laboratorio di Neurofisiologia del C.N.R., Pisa, Italy

References and Notes

1. H. B. Barlow, C. Blakemore, J. D. Pettigrew, *J. Physiol. (London)* **193**, 327 (1967); T. Nikara, P. O. Bishop, J. D. Pettigrew, *Exp. Brain Res.* **6**, 353 (1968); J. D. Pettigrew, T. Nikara, P. O. Bishop, *ibid.*, p. 391.
2. L. A. Riggs, E. P. Johnson, A. M. L. Schick, *Science* **144**, 567 (1964); ———, *J. Opt. Soc. Amer.* **56**, 1621 (1966); W. A. Cobb, H. B. Morton, G. Ettlinger, *Nature* **216**, 1123 (1967); F. W. Campbell and L. Maffei, *J. Physiol. (London)* **207**, 635 (1970); L. Maffei and F. W. Campbell, *Science* **167**, 386 (1970).
3. C. Blakemore, in preparation; A. Fiorentini and L. Maffei, in preparation.
4. When this paper was ready for publication another paper appeared [D. Regan and H. Spekreijse, *Nature* **225**, 92 (1970)] in which findings in good agreement with our conclusions were presented.

27 January 1970

Cognitive Model of Problem-Solving in Chess

Abstract. *By performing a series of five experiments with two subjects, several aspects of one of the subject's behavior in solving chess problems were found to be predictable, and a model was developed to explain this predictability. The heuristics used in this model may be applicable in developing future computer programs for chess play.*

Newell and Simon (*1*) have developed a methodology for analyzing the cognitive processes of a human chess player. By inducing a subject to "think out loud" while he is deciding on a chess move, a protocol of the subject's thinking, as he explores alternative moves, can be obtained. This protocol can then be analyzed into a number of episodes or sequences of moves and possible countermoves generated from an initial or base move postulated by the player. It is then possible to draw out from these episode sequences a decision tree or trees—such as are discussed in descriptions of Bayesian statistics—stemming from an initial base move (or moves) and comprising all the possible moves by the player and countermoves by the opponent considered by the player. The aim of this enterprise is to understand an individual's cognitive processes when he is playing chess and to make accurate predictions based on that understanding.

With this methodology, the protocols obtained when a subject analyzed the same middle game position used by Newell and Simon, two end game positions, a position arrived at after an actual game with another subject had been stopped at an arbitrary point, and a middle game position and its reverse (that is, diagonally inverted so that the black pieces were now white and vice versa) were studied. These positions were taken from Fine and De Groot (*2*). The subjects were male graduate students and class C chess experts. The data from only one of these subjects are presented here, since only one protocol was collected from the other subject. One of the aims of these experiments was to explore the implications of these different chess positions for the subject's decision-making process, but extensive analysis showed no significant relation between the type of chess problem and the subject's decision rules (*3*).

A second objective of the research was to test the generality of six rules suggested by Newell and Simon as having been used by their subject for generating a sequence of episodes or decision-tree explorations. These rules for episode sequence were as follows.

1) The analysis of each base move is independent of the analysis of other base moves, except that it can be interrupted by other activity. That is, each episode in the analysis of a base move is determined only by the results of the prior episodes of that base move.

2) The first episode of the base move employs normal curves, and subsequent episodes utilize increasingly unusual moves.

3) If the evaluation of an episode gives a favorable result, then an analysis of its base move is continued; if the evaluation is unfavorable, a different base move is analyzed.

4) When one is exploring, moves for the opponent may be considered that are favorable to self (in order to place an upper bound on the possibilities).

5) The analysis of a base move will be interrupted to pursue other moves, discovered during the episode, that seem to have merit either for self or for the opponent.

6) Before a base move is finally chosen, a check is made for other alternative base moves.

Table 1. Confirmations and disconfirmations of rules proposed by Newell and Simon. The units counted here are episodes. In our study we defined an episode as any exploration tree beginning with a base move, that is, a move that must be taken from the list of moves immediately available to the player. This is a slight modification of the Newell and Simon definition which permits some episodes to begin without returning to the base move, provided there is a break in the protocol. These differences did not significantly affect the results.

	Rules					
	1	2	3	4	5	6
Newell and Simon subject						
Confirmations	11	15	16	5	4	1
Disconfirmations	0	1	2	0	0	1
No application	14	9	7	20	21	23
Scurrah and Wagner subject						
Confirmations	75	76	71	12	15	12
Disconfirmations	5	3	53	0	1	4
No application	58	59	14	126	122	122

Table 1 shows the extent to which the protocols from their subject and ours confirmed or disconfirmed these rules. Rules 1, 2, and 3 were widely used by both subjects and had a high proportion of confirmations, while rules 4, 5, and 6 were also confirmed but were used so little as to be of questionable importance. Thus, in general, the subjects in both studies followed the modified progressive deepening strategy outlined by Newell and Simon.

This suggested that further analysis of the data might lead to the formulation of a more precise set of rules. Newell and Simon's rule 3 was widely applied by the subjects in both studies but had a low order of confirmation for our subject. More detailed analysis (*3*) reveals that of the 53 disconfirmations, 39 concern a negative evaluation of an episode followed by an analysis of the same base move, compared with 14 concerning a positive evaluation followed by an analysis of a new base move. The most plausible explanation seems to be that, after his preliminary survey of the board, our subject usually found a particular base move that looked most likely to yield a positive evaluation and continued exploring it, despite negative evaluations. The following more detailed rules for move and episode generation were therefore derived and tested.

1a) If the evaluation is negative, the first new move in the next branch or episode will be made by the subject.

1b) If the evaluation is positive, the first new move in the next branch or episode will be made by the opponent.

2) A generated new move will replace the last move made by the opponent or subject in accordance with rule 1. In a few cases, the second-to-last move, rather than the last one, will be replaced.

3) If the evaluation is negative and

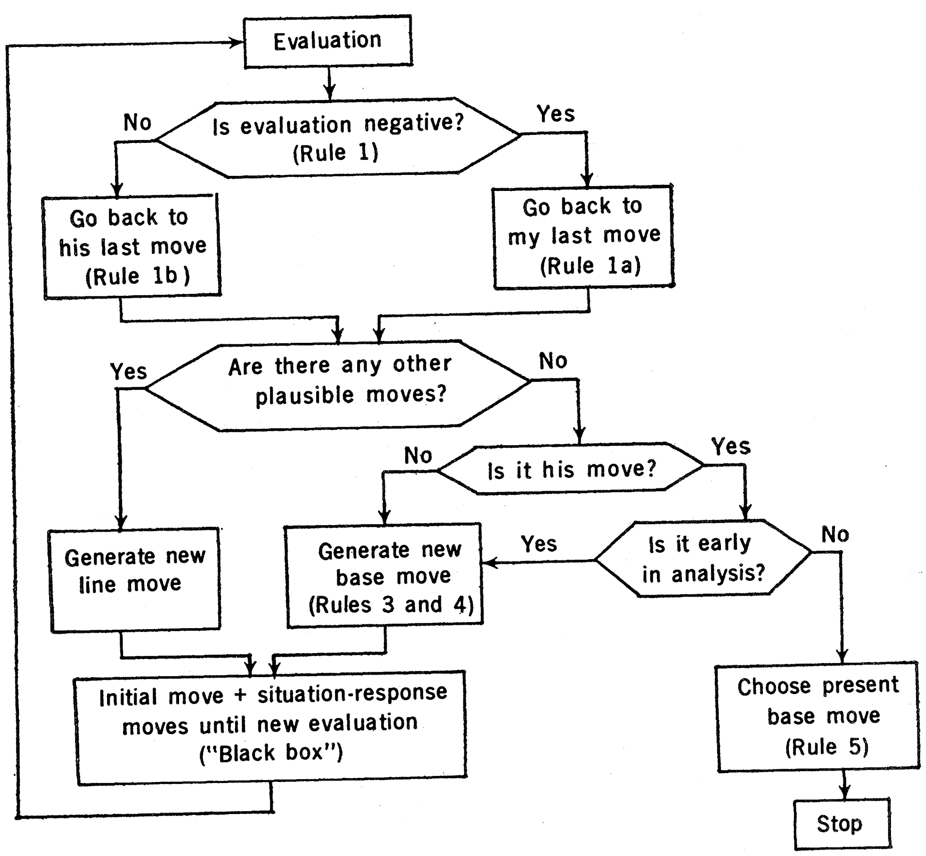

Fig. 1. Flow chart of cognitive decision process in chess.

Table 2. Confirmations and disconfirmations of rules for move and episode generation. The units counted here are again episodes. However, since we are presenting data for the five rules for move and episode generation combined there will in many cases be more than one confirmation or disconfirmation per episode. Hence, the total instances recorded here for Newell and Simon's subject (34) exceeds the total recorded in the previous table (25).

	Positions					
	Middle	End	Real game	End	Middle	Reverse
	Newell and Simon subject					
Primary confirmations	28					
Secondary confirmations*	1					
Disconfirmations	5					
	Scurrah and Wagner subject					
Primary confirmations	85	20	15	37	21	11
Secondary confirmations*	5	1	0	1	1	0
Disconfirmations	1	0	3	5	2	0

*These represent those cases in which the second-to-last move, rather than the last one, was replaced (see rule 2 for move and episode generation).

all plausible line moves have been considered, the new move generated will be a new base move.

4) If the evaluation is positive and the subject has made an early tentative decision on the best or most favored base move, he may switch to a new base move.

5) If the evaluation is positive and all plausible line moves have been considered, the present base move will be chosen by the subject.

Rule 2 is disconfirmed if a generated new move replaces neither the last nor the second-to-last move. In rules 3 and 5 all plausible line moves have been considered when the subject makes some statement which indicates exhaustion of plausible line moves as he sees them. Again, in rule 4 a judgment that the subject has made an early tentative decision on the best or most favored move is made on the basis of some statement of his to that effect.

As Table 2 shows, these rules have a larger number of applications in the protocols of both subjects, and, while the percentage of confirmations declines slightly from 90 to 85 for the Newell and Simon subject, it rises sharply from 57 to 95 for our subject when we compare Newell and Simon's rule 3 with our four more detailed rules.

If one combines Newell and Simon's rules 1 and 2 with our move and episode generation rules and if one assumes that a system of situation-response moves along the lines of the 19 rules suggested by Newell and Simon in their Table II brings the subject along his tree of exploration to the point where he evaluates the base move he is considering, a flow chart of the move and episode generation process can be drawn up (see Fig. 1). This seems to be a fairly close representation of part of the decision process of these two subjects. The "black box," which needs further analysis, is the system of situation-response moves which brings the subject from his initial choice of a base move to be analyzed through a series of hypothetical responses by himself and his opponent to the point in the exploration tree where he considers an evaluation is in order. We suspect that the responses are made to situational clues that trigger countermoves that are stored in the memory on the basis of previous chest games or reading of chess literature. Thus, for example, the situational clue, "man attacked," might call forth the response, "counter-attack of equal value." The addition of rules for these two parts of the decision-making process in chess—the initial choice of a base move and the system of moves to the evaluation point—are a logical next step in research and would result in a complete cognitive model of the chess decision process.

While the cognitive model proposed is not a complete one, it does seem to explain significant proportions of the decision process and may well indicate heuristics that could be used in writing computer programs for chess play.

MARTIN J. SCURRAH
DANIEL A. WAGNER
Graduate School of Business and Public Administration, Cornell University, Ithaca, New York 14850

References and Notes

1. A. Newell and H. A. Simon, in *Progress in Biocybernetics*, N. Weiner and J. P. Schade, Eds. (Elsevier, Amsterdam, 1965), pp. 19–75.
2. R. Fine, *The Middle Game in Chess* (McKay, New York, 1952), p. 439; A. D. De Groot, *Thought and Choice in Chess* (Mouton, The Hague, 1965), positions A, B, and PB-6.
3. M. J. Scurrah and D. A. Wagner in preparation.

12 January 1970

Denver Earthquakes

The recent exchange between Karp and Simon (*1*) prompts us to comment on the results of short-period seismograph observations at the University of Colorado at Boulder, some 40 km west-northwest of the Rocky Mountain Arsenal well. This station was operated from April 1954 to November 1959; it was reactivated in November 1965 and has been kept in operation to the present. The instruments used since May 1966 are the same as those that were in operation during the 1950's.

Observations made since 1965 show that events at Derby of magnitude 1.5 on Major and Simon's listings (*2*) can often be detected at Boulder but would not be distinguished from background noise in the absence of these listings. Events of magnitude 1.8 usually stand out well from the background noise, and events of magnitude 2.0 or greater give clear and distinctive traces. A systematic search through records from the earlier period of observation has failed to reveal a single event showing the characteristics of modern Derby earthquakes. Events thought by Krivoy and Lane (*3*) possibly to be Derby earthquakes have been definitely identified as artificial explosions.

The average frequency of Derby earthquakes of magnitude greater than 2.0 was about four per month between 1962 and 1968. Hence, we conclude that earthquake activity at the Arsenal during the 1950's, if there was any, must have been nearly two orders of magnitude less than during, and immediately after, the pumping of the disposal well.

J. C. HARRISON
W. W. LONGLEY
Department of Geological Sciences, University of Colorado, Boulder 80302

References

1. E. Karp, *Science* **167**, 1518 (1970); R. B. Simon, *ibid.*, p. 1519.
2. M. W. Major and R. B. Simon, *Colo. Sch. Mines Quart.* **63**, 9 (1968).
3. H. L. Krivoy and M. P. Lane, in "Geophysical and Geological Investigations Relating to Earthquakes in the Denver Area, Colorado" (U.S. Geological Survey Open File Report, 22 March 1966).

17 April 1970