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Research Report

THE ROLES OF RECOGNITION PROCESSES AND LOOK-AHEAD SEARCH IN TIME-CONSTRAINED EXPERT PROBLEM SOLVING: Evidence From Grand-Master-Level Chess

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Abstract—*Chess has long served as an important standard task environment for research on human memory and problem-solving abilities and processes. In this article, we report evidence on the relative importance of recognition processes and planning (look-ahead) processes in very high level expert performance in chess. The data show that the rated skill of a top-level grand master is only slightly lower when he is playing simultaneously against a half-dozen grand-master opponents than under tournament conditions that allow much more time for each move. As simultaneous play allows little time for look-ahead processes, the data indicate that recognition, based on superior chess knowledge, plays a much larger part in high-level skill in this task than does planning by looking ahead.*

For the past 20 years, there has been a general consensus, based on extensive laboratory research, that two psychological mechanisms play a principal role in skilled chess-playing performance. The first mechanism is *recognition* of cues in chess positions that evoke information from the expert's memory about possible moves and other implications of recognized patterns of pieces. The second mechanism is planning by *looking ahead* at possible moves, possible responses by the opponent, possible responses to those responses, and so on. The chess-based model of expertise, emphasizing a combination of recognition and selective search processes, has been applied widely to the explanation of expertise in other domains involving complex specialized skills: medical diagnosis, engineering and architectural design, and many others (Charness, 1992; Ericsson & Staszewski, 1989). The validity of this model is consequently of considerable interest and importance for the general understanding of the nature of expert performance.

The role of recognition processes in chess-playing skill was first recognized by De Groot (1946/1978), and studied further by Chase and Simon (1973), Simon and Chase (1973), Goldin (1979), Charness (1981a, 1981b), Hartston and Wason (1983), Saariluoma (1985, 1989), Lories (1987), Gobet (1993), and others. A key experimental result is that positions in chess games (with about 25 pieces on the board) can be stored in memory and reconstructed almost perfectly by masters and grand masters after as little as a 5-s view of the board; in contrast, under these same conditions, weak players can recall only some half-dozen pieces. As this superiority of masters over weaker players nearly vanishes if the pieces are placed at random on the board instead of coming from positions in an actual game, it appears that the masters are recognizing and storing familiar patterns of pieces, rather than individual pieces (Chase & Simon, 1973). From these experiments, one can conclude that the recognition process requires, at most, 1 to 5 s, in consistency with recognition processes in other tasks.

The significance of recognition is that chess masters, on noticing that the board before them contains particular chunks, thereby gain long-term memory access in a matter of seconds to the whole rich body of information that, through previous training and experience, has been associated with, hence is cued by, the chunks (De Groot, 1946/1978). For example, on recognizing that a particular position represents the Dragon variation of the Sicilian defense, a well-known line of play, masters access a template giving the typical locations of a dozen or more pieces in the Dragon and probable locations of other pieces, as well as extensive knowledge of moves and strategies (successful and unsuccessful) that have been tried in similar positions in the past. The recognition mechanism provides a rapid index to the master's chess knowledge and tools of analysis (De Groot, 1946/1978; Gobet & Simon, 1994b). This mechanism has been incorporated in a computer program described by Gobet and Jansen (1994): Patterns of pieces on the board, when recognized, suggest potential moves to the program.

The role of search processes in chess has always been acknowledged, but De Groot (1946/1978) contributed greatly to the understanding of them by demonstrating that even chess grand masters seldom look at more than 100 possible continuations of the game before choosing a move. As the number of possible legal moves in a middle-game position averages about 35, the number of legal continuations 3 moves deep for each player is typically about 35^6 (1.8 billion), and the number of legal continuations continues to increase exponentially for greater depths. Thus, look-ahead search is highly selective and closely guided by chess knowledge.

A surprising result in De Groot's study (1946/1978) was that top-level grand masters[1] do not search reliably deeper than experts. In a direct replication of De Groot's experiment, masters did not differ from somewhat less skilled players in their maximal depth of search, but searched deeper, on average, than weak amateurs (Class B players; Gobet, 1994). Differences in search have also been reported by Charness (1981b) and Holding and Reynolds (1982), using experimental positions different from de Groot's (1946/1978), but the increase in depth of aver-

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1. Players are ranked by a so-called Elo scale as grand masters (2500 and above), masters (2200–2499), experts (2000–2199), Class A players (1800–1999), Class B players (1600–1799), and so on. The Elo scale is described later in the text.

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age search as a function of skill was relatively small, about 0.5 half-moves for each standard deviation (200 Elo points). Given that the best players in those studies were clearly weaker than De Groot's (1946/1978) grand masters, who did not differ in amount of search from their weaker colleagues, Charness's (1981) proposal that the search algorithms become uniform at high skill levels (perhaps master level) seems valid.

Although the significance of both recognition and search mechanisms is generally accepted, there is not full agreement as to their relative importance. Some researchers (De Groot 1946/1978; Simon & Chase, 1973) have proposed that recognition, by allowing knowledge to be accessed rapidly, allows the slower look-ahead search to be greatly abridged or even dispensed with entirely without much loss in quality of play. Holding (1985), by contrast, argued that the main determinant of chess skill is ability to plan ahead by search, rather than reliance on recognition of positional patterns. Specifically, he concluded that

> the differences between players at different levels of skill seem to be attributable to differences in the cognitive activities described by the search-and-evaluation theory. The better players show greater competence in every phase of the [search] processes, conducting more knowledgeable and better planned searches, with more knowledgeable evaluations, in order to anticipate events on the chessboard. (pp. 255–256)

The data reported in this article test Holding's conclusion.

One way to measure the relative importance of recognition and search is to compare the quality of play of masters and grand masters under normal tournament conditions with the quality of play under the conditions of rapid chess or of simultaneous play, in which there is little time for extensive look-ahead search. Analysis of masters' and grand masters' rapid and simultaneous games shows that they can play excellent chess even in these difficult conditions. Quantitative accounts of their performance are, however, rare. We have discovered only one published study that bears on this question: Calderwood, Klein, and Crandall (1988) showed that there was no substantial difference in the quality of moves, as rated by a grand master, between games played under regular conditions (in this experiment, 2.25 min per move, on average) and games played under blitz conditions (5 min for the whole game, or an average of 6 s per move for games 50 moves long).

As this finding depends on a subjective (albeit expert) evaluation of the quality of moves, we have sought a more objective test. We report here our findings of a comparison between regular and simultaneous chess. These findings provide strong support for a dominant role of recognition as compared with search in determining the level of play. The findings are especially interesting in that the simultaneous player involved, Gary Kasparov, has the world's highest chess rating.

A NATURAL EXPERIMENT

Under typical tournament conditions, the player is allowed, on average, 3 min for each move. Failure to keep within the limit (enforced, e.g., as 20 moves in each hour) forfeits the game. The player may spend a quarter-hour, or more, deliberating about a single difficult move, but must then make up the time by making other moves rapidly. In any event, the 3-min rule allows time for substantial look-ahead search. Data from chess experiments show that a chess master might examine 100 branches of the game tree in 15 min, an average rate of about 9 s per branch. De Groot (1946/1978) found that stronger and weaker players examine nearly the same number of branches, but that the stronger players select more relevant and important branches—again, because of their greater ability to recognize significant features.

In the simultaneous play that we examine, the grand master (the present Professional Chess Association world champion, Gary Kasparov) played against four to eight opponents with a limit of 3 min (on average) for each round—that is, for each four to eight moves. His opponents were allowed an average of 3 min for each move in reply. Hence, Kasparov, in these simultaneous matches, was allowed only one quarter to one eighth of the normal tournament time for making moves, while his opponents were allowed the full tournament time.

The simultaneous player with only 30 s, say, for a move will have little time for extensive look-ahead search[2] at 9 s per branch, and will have to depend primarily on recognition of cues to select the right moves. In fact, this is what grand masters who engage in simultaneous matches report: that they make "standard" (i.e., familiar) developing moves until they notice a cue that informs them that an opponent has created a weakness in his or her position. Knowledge associated with, and evoked by, the recognized cue then suggests effective moves for exploiting the weakness and creating difficulties for the opponent. Only a few recognized mistakes by the opponent ("mistakes" that the grand master but not the opponent recognizes as such) are enough for an easy win.

The skill of chess players is measured by an official scale, devised by Elo (1978), which has been used by the chess world for more than 20 years. On the Elo scale, players with ratings of 2500 and above are called grand masters, and players with ratings of 2200 to 2499, masters. At the time he played the games we consider here, Kasparov had a rating of about 2750. A player can usually defeat players whose ratings are 300 or more Elo points lower than his own rating, will draw with them occasionally, and will lose to them only rarely.

The win of a chess game is assigned the value 1, a loss, 0, and a draw, 1/2. If a simultaneous player won four games against six opponents, lost one, and drew one, he would score 4.5 and his opponents would score 1.5. Thus, the ratio of the player's score to the total score of the opponents would be three to one. If the average Elo rating of the opponents was 2450, and the rating of the simultaneous player was 2750, Elo's linear approximation formula yields for the latter a performance rating of 2650 (2450 + 400[4.5 − 1.5]/6) under the conditions of simultaneous play. The level of his simultaneous play would

2. The explanation that Kasparov maintains his strength against several players by suddenly increasing his rate of generating possible moves during search may be discarded at once: If he were able to do so, there is no reason why he would not search at this higher rate in normal competition. Nor can he restore his ability to search deeply by allocating almost all his time to a few critical moves. He still faces the fact that he has only one quarter to one eighth of the normal tournament time in order to do this, and the scope of his searches would therefore be reduced severely.

Table 1. *Kasparov's performance in simultaneous chess against various national teams and the Hamburg team, one of the top teams of Germany*

Team	Number of opponents	Date	Opponents' mean Elo	Kasparov's score	Kasparov's performance[a]
Hamburg (Match 1)	8	Dec. 1985	2358	3.5–4.5	2310
Hamburg (Match 2)	8	Feb. 1987	2354	7.0–1.0	2682
Switzerland	6	May 1987	2394	5.5–0.5	2786
United States (junior team)	6	Feb. 1988	2453	4.0–2.0	2570
France (Match 1)	6	Dec. 1988	2320[b]	4.5–1.5	2513
France (Match 2)	6	June 1989	2425	4.5–1.5	2618
Germany	4	Jan. 1992	2550	3.0–1.0	2743
Argentina (Match 1)	6	Oct. 1992	2433	4.0–2.0	2550
Argentina (Match 2)	6	Oct. 1992	2433	5.0–1.0	2710

Note. These results, including the games palyed during these matches, can be retrieved from various publicly available databases, such as ftp://chess.onenet.net/pub/chess/Game-Databases/PGN/Players/Kasparov.pgn.gz. For the Elo points, we used the lists published biannually by the FIDE (International Chess Federation), Athens.

[a] Median = 2618.

[b] One opponent was rated at 1850, which biased Kasparov's performance downward. Computed without this opponent, his performance reaches 2564.

then be only 100 Elo points inferior to the level of his play under tournament conditions. An Elo rating of 2650 is very high; even among grand masters, only a half dozen players in the world equal or exceed that level.

RESULTS

We have summarized in Table 1 the scores for a number of matches that Kasparov played against national teams and the strong German team of Hamburg, each comprising leading players with high chess talents. The opposing players, almost without exception, were masters or grand masters. Kasparov obtained results, rather consistently, close to those described in the previous paragraph. Playing without the opportunity for much look ahead, hence relying primarily on his ability to recognize cues that signaled opponents' mistakes, Kasparov played at the level of a very strong grand master—as a matter of fact, often less than 100 points below his level in tournament play. There was no correlation between the number of opponents (hence the average speed with which Kasparov had to play) and his estimated performance.

Given the strength of the opposition, Kasparov could not rely only on playing normal moves and waiting for opponents' mistakes. Preparation also played an important role in his performance (as it does in serious tournament play). In most of the encounters, Kasparov required the event's organizers to provide him with about a hundred games of each of his opponents. He then studied these games with the help of a computer chess database program, to identify his opponents' weaknesses and strengths.[3] During the matches, he might then try to steer the play into types of positions that did not suit a particular opponent, increasing the likelihood of the opponent's making mistakes.

For example, faced with an opponent who does not like endgames (positions with few pieces remaining on the board), and the choice between a balanced middle game or a balanced (or even slightly worse) endgame, Kasparov would choose the latter alternative. Such knowledge of opponents' preferences allows him to limit his real-time search to particular types of positions, reducing the search space for moves. Two comments can be added. First, before his first match against Hamburg, as compared with the second one, Kasparov did not make as extensive a study of his opponents' styles, which may explain in part his poorer performance. (For similar reasons, his performance improved in his second matches against the teams of France and Argentina). Second, although his opponents had also studied Kasparov's games, they were not generally able to use their knowledge of his play as effectively, because their own command of chess tactics and strategies was substantially inferior to his.

In view of the slight extent to which the lack of time for search lowered the quality of Kasparov's play in the simultaneous matches, we conclude that memory and access to memory through the recognition of clues is the predominant basis for his skill, and almost certainly for the skill of the other grand masters of the game.

These findings suggest that in extending knowledge of expertise, it will be important to determine whether recognition of patterns, based on accumulated knowledge, plays a dominant role (and analysis by search, although indispensable, a secondary role) in other frequently repeated professional tasks, such as medical diagnosis and engineering design. It will also be important to discover how the balance of recognition and search depends on the severity of real-time limits that constrain the expert in different professional tasks.

3. For a detailed description of Kasparov's preparation, as well as of other chess-related aspects of the simultaneous matches, see Kasparov (1993a, 1993b, 1993c, 1993d, 1994).

Acknowledgments—This research was supported by the National Science Foundation, Grant No. DBS-9121027; by the Defense Advanced Research Projects Agency, Department of Defense, ARPA Order 3597, monitored by the Air Force Avionics Laboratory under Contract F33615-81-K-1539; and by the Swiss National Science Foundation, Grant No. 8210-30606. Reproduction in whole or in part is permitted for any purpose of the U.S. government. Approved for public release; distribution unlimited.

We are grateful to James Altucher, Harald Hofmeister, Stefan Kahrs, and Reinhard Knab for helping us to keep track of Kasparov's results, and to Adriaan De Groot and Pertti Saariluoma for helpful comments on an earlier draft.

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(RECEIVED 11/28/94; ACCEPTED 2/8/95)