The Roles of Recognition Processes and Look-Ahead Search in Time-Constrained Expert Problem Solving: Evidence From Grand-Master-Level Chess — Source link

Fernand Gobet, Herbert A. Simon

Institutions: Carnegie Mellon University

Published on: 01 Jan 1996 - Psychological Science (SAGE Publications)

Topics: Chunking (computing), Task (project management) and Pattern recognition (psychology)

The Roles of Recognition Processes and Look-Ahead Search in Time-Constrained Expert Problem Solving: Evidence from Grandmaster Level Chess

Fernand Gobet and Herbert A. Simon
Carnegie Mellon University

Gobet, F. & Simon, H. A. (1996). The roles of recognition processes and look-ahead search in time-constrained expert problem solving: Evidence from grandmaster level chess. *Psychological Science, 7,* 52-55.

Running head: RECOGNITION AND SEARCH IN SIMULTANEOUS CHESS

Abstract

Chess has long served as an important standard task environment for research on human memory and problem-solving abilities and processes. In this paper, 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 grandmaster is only slightly lower when he is playing simultaneously against a half dozen grandmaster 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.

The Roles of Recognition Processes and Look-Ahead Search In Time-Constrained Expert Problem Solving: Evidence from Grandmaster Level Chess

For the past twenty years there has been a general consensus, based on extensive laboratory research, that two psychological mechanisms play a principal role in skilled chessplaying 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 familiar 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: for example, 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 our general understanding of the nature of expert performance.

The role of recognition processes in chessplaying skill was first recognized by Adriaan de Groot (1949/1978), and studied further by Chase and Simon (1973), Simon and Chase (1973), Goldin (1979), Charness (1981a,b), 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 grandmasters after as little as five seconds' view of the board; while, 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 was concluded that the masters were recognizing and storing familiar patterns of pieces when these were present, rather than individual pieces (Chase & Simon, 1973). From these experiments, we can conclude that the recognition process requires, at most, one to five seconds, 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). 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 positions of a dozen or more pieces in the Dragon and probable positions of others, 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; Gobet & Simon, 1994a). 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 (1949) contributed greatly to our understanding of them by demonstrating that even chess grandmasters seldom look at more than 100 possible continuations of the game before choosing a move. As the number of legal moves in a middlegame position averages about 35, the number of legal continuations three moves deep for each player is typically about $35^6 = 1.8$ billion, and 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 (1949) was that top-level grandmasters do not search reliably deeper that amateurs. In a direct replication of de Groot's experiment, Gobet (1994) found that masters did not differ from somewhat less skilled players in their maximal depth of search, but that they searched deeper, on average, than weak amateurs. Differences in search have also been reported by Charness (1981b) and Holding and Reynolds (1982), using experimental positions different from de Groot's (1949); but the increase in depth of average search as a function of skill is relatively small, about 0.5 half-move for each standard deviation (200 Elo points; see below for a description of the Elo scale). Given that the best players in those studies were clearly weaker than de Groot's (1949) grandmasters, who did not differ in amount of search from their weaker colleagues, Charness' (1981) proposal that the search algorithms become uniform at high skill levels seems valid.

Although the significance of both recognition and search mechanisms is generally accepted, there is not full agreement as to their relative importance. De Groot (1949) as well as Simon and Chase (1973) propose 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 (pp. 255-56) that "[t]he 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." The data reported in this paper test that conclusion.

One way to measure the relative importance of recognition and search is to compare the quality of play of masters and grandmasters under normal tournament conditions with its quality under the conditions of rapid chess or of simultaneous play where there is little time for extensive look-ahead search. Analysis of Masters' and Grandmasters' 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. As to rapid chess, Calderwood & al. (1988) showed that there was no substantial difference in the quality of moves, as rated by a grandmaster, between games played under regular conditions (in their experiment, 2.25 min. per move, on average) and games played under blitz conditions (5 minutes for the whole game, or an average of 6 seconds 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 the findings of such a comparison in simultaneous chess that provides 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, three minutes for each move. Failure to keep within the limit (enforced, for example, as 20 moves in each hour) forfeits the game. Players may spend a quarter-hour, or more, deliberating about a single difficult move, but they must then make up the time by making other moves rapidly. In any event, the three-minute 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 fifteen minutes, an average rate of about nine seconds per branch. De Groot's (1946) 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 shall examine, the grandmaster (the present PCA-world champion, Gary Kasparov) played against four to eight opponents with a limit of three minutes (on average) for each *round* -- that is, for each four to eight moves. His opponents were allowed an average of three minutes for each move in reply to Kasparov's. 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.

Given these time constraints, the simultaneous player, with only 30 seconds, say, for a move, will have little time for extensive look-ahead search[1] at 9 sec per branch, and will have to depend primarily on recognition of cues to select the right moves. In fact, this is what grandmasters who engage in simultaneous matches report: that they make "standard" (i.e., familiar) developing moves until a cue is noticed that informs them that an opponent has created a weakness in his or her position. Knowledge associated with, and evoked by, the recognized cue now suggests effective moves for exploiting the weakness and creating difficulties for the opponent. Only a few recognized mistakes by the opponent ("mistakes" that the grandmaster 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 Arpad Elo (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 grandmasters, and players with ratings of 2200-2499, masters. At the time he played the games we will consider, Kasparov had a rating of about 2750. A player can usually defeat players whose ratings are 300 or more Elo points lower, draw with them occasionally, and 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 player won four games against six opponents, lost one, and drew one, he would score 4.5:1.5, or a ratio of three to one against the average of the opponents. If the average Elo rating of the opponents was 2450, and the rating of the simultaneous player 2750, we could use Elo's linear approximation formula to estimate for the latter a performance rating of 2450 + 400 (4.5 - 1.5) / 6 = 2650 under the conditions of simultaneous play. The level of his simultaneous play would 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 grandmasters, 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 of a country with high chess talents. The opposing players, almost without exception, were masters or grandmasters. 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 grandmaster -- 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.

Insert Table 1 about here

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[2]. During the game, 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 an equal middle game or an equal (or even slightly worse) endgame, Kasparov would choose the latter alternative. This knowledge 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, Kasparov did not make an extensive study of his opponents' styles, which may explain in part his poorer performance (and for similar reasons, his improved performance in his second match against the teams of France and Argentina). Second, although his opponents have also studied Kasparov's games, they are not generally able to use their knowledge of Kasparov's play as effectively, because their own command of chess tactics and strategies is substantially inferior to his.

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

These findings suggest that in extending our knowledge of expertise it will be important to determine whether recognition of patterns, based on accumulated knowledge, also 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; and also to discover how the balance of recognition and search depends upon the severity of real-time limits that constrain the expert in different professional tasks.

References

Calderwood, B., Klein, G. A., & Crandall, B. W. (1988). Time pressure, skill, and move quality in chess. *American Journal of Psychology, 101,* 481-493.

Charness, N. (1981a). Aging and skilled problem solving. *Journal of Experimental Psychology: General, 110,* 21-38.

Charness, N. (1981b). Search in chess: Age and skill differences. *Journal of Experimental Psychology: Human Perception and Performance*, *2*, 467-476.

Charness, N. (1992). The impact of chess research on cognitive science. *Psychological Research, 54,* 4-9.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology*, *4*, 55-81.

De Groot, A. D. (1946). *Het denken van den schaker*. Amsterdam, Noord Hollandsche.

De Groot, A. D. (1978). *Thought and choice in chess* (2nd ed.). The Hague: Mouton Publishers. (Revised translation of De Groot, 1946).

Elo, A. (1978). *The rating of chessplayers, past and present.* New York: Arco.

Ericsson, K. A., & Staszewski, J. J. (1989). Skilled memory and expertise: Mechanisms of exceptional performance. In D. Klahr. & K. Kotovsky (Eds.), *Complex information processing: The impact of Herbert A. Simon.* Hillsdale, NJ: Erlbaum.

Gobet, F (1993). *Les mémoires d'un joueur d'échecs*. [Chess players' memories]. Fribourg (Switzerland): Editions Universitaires.

Gobet, F. (1994). *Has chess players' thinking changed in the last fifty years?* Unpublished manuscript.

Gobet F. & Jansen, P. (1994). Towards a chess program based on a model of human memory. In H. J. van den Herik, I. S.Herschberg, & J.E. Uiterwijk (Eds.), *Advances in Computer Chess 7*. Maastricht: University of Limburg Press.

Gobet, F. & Simon, H. (1994 a). *Templates in chess memory: A mechanism for recalling several boards*. Complex Information Processing Paper #513, Department of Psychology, Carnegie Mellon University.

Gobet, F. & Simon, H. (1994 b). *Chunks in chess memory: Recall of random and distorted positions.* Complex Information Processing Paper #518, Department of Psychology, Carnegie Mellon University.

Goldin, S. E. (1979). Recognition memory for chess positions : Some preliminary research. *American Journal of Psychology, 92*, 19-31.

Hartston, W. R. & Wason, P. C. (1983). *The psychology of chess.* London: Batsford.

Holding, D. H. (1985). *The psychology of chess skill.* Hillsdale, NJ: Erlbaum.

Holding, D.H. & Reynolds, R.I. (1982). Recall or evaluation of chess positions as determinants of chess skill. *Memory & Cognition, 10,* 237-242.

Lories, G. (1987). Recall of random and non random chess positions in strong and weak chess players. *Psychologica Belgica, 27,* 153-159.

Saariluoma, P. (1985). Chess players' intake of task-relevant cues. *Memory & Cognition, 13*, 385-391.

Saariluoma, P. (1989). Chess players' recall of auditorily presented chess positions. *European Journal of Cognitive Psychology, 1*, 309-320.

Simon, H. A., & Chase, W.G. (1973). Skill in chess. *American Scientist*, *61*, 393-403.

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 F336l5-81-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 United States 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.

Correspondence concerning this article should be addressed to Herbert A. Simon, Department of Psychology, Carnegie Mellon University, Pittsburgh, Pennsylvania, 15213.

Footnotes

[1]The explanation that Kasparov maintains his strength against several players by suddenly increasing his rate of generating moves 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.

[2]For a detailed description of Kasparov's preparation, as well as of other chess-related aspects of the simultaneous matches, see G. Kasparov: Simuls in my Life, *Chess Life*, issues from September 1993 to January 1994.

Table 1.

Kasparov's performance in simultaneous chess against various national teams and against Hamburg, one of the top teams of Germany. In each encounter, Kasparov had white pieces in half of the games, and black pieces in the other half. (Sources: *ChessLife, Die Schachwoche, Europe-Echecs, Schach-Report).*

Team	Number of opponents	Date	Opponents' Mean Elo[a]	Kasparov's score	Kasparov's performance
Hamburg (1)	8	Dec. 1985	2358	3.5 - 4.5	2310
Hamburg (2)	8	Feb. 1987	2354	7.0 - 1.0	2682
Swiss Team	6	May 1987	2394	5.5 - 0.5	2786
USA Junior Team	6	Feb. 1988	2453	4.0 - 2.0	2570
French Team (1)	6	Dec. 1988	2320[b]	4.5 - 1.5	2513
French Team (2)	6	June 1989	2425	4.5 - 1.5	2618
German Team	4	Jan. 1992	2550	3.0 - 1.0	2743
Argentina Team (1)	6	Oct. 1992	2433	4.0 - 2.0	2550
Argentina Team (2)	6	Oct. 1992	2433	5.0 - 1.0	2710[c]

[a] Official international ELO ratings are used.

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

[c] Median = 2646