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# 166 Chess expertise

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# 166 Chess Expertise

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## Introduction

Expertise may be defined as the ability of some individuals to perform at levels vastly superior to the majority. For historical and scientific reasons, research on chess expertise has played a major role in the study of expertise in general.

The first reason is that chess itself has a very long history (the modern form of western chess goes back to the 16th century). This has made possible an extensive study of the game, leading to the development of several "theories" about the proper way to play by leading players such as Steinitz, Nimzowitch, and Euwe. Next, the rules of chess offer a well-specified and constrained environment, that is easily formalizable. Chess is also a game flexible enough to allow multiple experimental manipulations. In addition, the presence of a rating system (the Elo system) allows one to estimate players' skill quantitatively and precisely. Compared to most other domains of expertise, this ability to measure skill is a definite advantage. Contrast this situation with, for example, the study of experts in physics or medicine, where researchers have to use very rough classifications such as novice, intermediate, and expert. Finally, there has been rich cross-fertilization between psychological research on chess expertise and research in formal fields like computer science and mathematics.

### Chess in the Formal Sciences

Rather unsurprisingly, chess has been a favorite subject of study in the formal sciences. On several occasions, chess has been used to explore aspects of game theory; in a celebrated paper published in 1912, Zermolo formalized the concept of *game tree* and introduced the method of *backwards induction* with reference to chess. The game has also been of interest to mathematicians, for example in the field of combinatorics. However, most of the research has been made in artificial intelligence and computer science. If one ignores chess automata, most of which turned out to be fraudulent, computer chess started in earnest in 1949 with Shannon's paper describing a computer program able to play an entire game, either by full search to a specified depth or by selective search. Since that seminal work, researchers have extensively explored various techniques for improving the efficiency of search algorithms or to make search more selective (see Newell & Simon, 1972, or Levy & Newborn, 1991). The crowning achievement of the quest for efficient search algorithms (the so-called "brute-force" approach) was the development of Deep Blue, the first computer to beat a world champion in an official match. Deep Blue's special-purpose hardware allowed it to consider up to 200 million positions per second. By contrast, a nice example of the selective-search approach is a program written by Pitrat (1977), which uses heuristics to cut the search tree down to the same size as humans' (about 100 positions). Recently, computer chess has seen a strong interest in database theory and in the development and testing of machine-learning algorithms.

## Chess in the Social and Behavioral Sciences

Expert behavior in chess has attracted the attention of various social and behavioral sciences, including psychoanalysis, psychiatry, and sociology. Questions such as "Does extreme practice of a skill lead to madness?", "Why are women weaker than men at chess?", "Can oedipal pulsions lead to creativity?", "Why is there a high proportion of Jews among top players?" have been asked in these fields, although the answers offered are often controversial (Dextreit & Engel , 1981; Holding, 1985). In addition, chess has sometimes been used not as an object of study, but as a model. Two examples may suffice. In philosophy, Lasker developed a philosophical system (machology) based on the element of fight extant in a chess game. In linguistics, De Saussure made regular use of chess to illustrate the rule-like character of language. For instance, he drew an analogy between a chess game and the synchronic analysis of language: if somebody walks into a room where a chess game is being played, they can study and understand the position without knowing the moves leading to it.

## Psychological Studies of Chess Expertise

However, in none of the social and behavioral sciences mentioned above has chess had such an impact as in psychology, where it has been used as a standard task environment for exploring expertise (Simon & Chase, 1973). Several concepts, such as progressive deepening and selective search, and several experimental techniques, such as the use of verbal protocols and the use of recall tasks to study expertise, have their main source in chess research.

### Brief History of Psychological Research

The first psychological investigation of chess expertise was carried out at the end of the 19th century by Binet, who was interested in masters' ability to play a game, or even several games, without seeing the board. This work, using questionnaires and focusing on the search for chess players' hypothetical, and probably non-existent, concrete visual memory, does not have much impact nowadays. Nor does the work carried out in 1927 by Djakow, Petrowski and Rudik, who were the first psychologists to bring chess players into the laboratory. These Russians scientists, who gave a battery of psychometric tests to their subjects, were interested in the question of chess talent. Their tests measured various "faculties of mind", such as memory, attention, or combination power. It turned out that chess masters did not differ from lay-people on most of these tests, the exception being tasks of visual memory where the stimuli bear a strong resemblance to chess boards.

The next wave of research on chess psychology had a huge impact on expertise research and on cognitive psychology in general. It was the work of a single man, the Dutch psychologist and chess master Adriaan De Groot. In his doctoral thesis (1946), De Groot introduced two key methods (recall of briefly-presented positions, and analysis of verbal protocols collected during problem solving), which allowed him to uncover several key determinants of expertise. First, players of all levels are highly selective in their search. Even top-level players do not search much more than about one hundred positions during a fifteen-minute deliberation. Second, there exist almost no differences between the search behavior of world-class grandmasters and that of weaker players, as far as measures such as depth of search, breadth of search, or branching factor are concerned. Third, players of all levels visit the same variation several times when choosing a move, a phenomenon De Groot called *progressive deepening.* This behavior allows cognitive systems of limited capacity, such as those of humans, both to propagate information from a given branch of the search tree to other branches, and to overcome the limits of short-term memory (De Groot & Gobet, 1996). Fourth, masters are able to zoom into the key features of the problem at hand very rapidly. Fifth, chess masters normally judge a position based on a single feature, which can be either static (e.g., material balance) or dynamic (e.g., potential actions). This is in sharp contrast to computer programs, which typically use a polynomial function to combine a large number of features (Levy & Newborn, 1991). Sixth, chess masters have a remarkable memory for meaningful material taken from their domain, even when this material is presented for just a few seconds.

De Groot's work, and through it the ideas of the German psychologist Otto Selz, was important in shaping the revolution in cognitive psychology (Newell & Simon, 1972). As the cornerstone of most current research on expert behavior, it has spawned a large number of empirical studies, the most important of which are reviewed in the next section.

### Key Empirical Results

It is common to organize chess research along the following lines: perception; memory; knowledge; look-ahead search; and general intelligence. Research on *perception* has confirmed De Groot's earlier results, and has shown that players can identify, and memorize, critical patterns in a position even with presentation times below one second. Automatization also affects lower levels of perception: as shown by Saariluoma (1995), the speed with which chess pieces are recognized is a function of the level of expertise. Finally, eye-tracking studies have shown that chess masters have faster eye movements, cover more of the important squares on the board, and tend to look at the intersection of squares more often than weaker players (De Groot & Gobet, 1996).

Empirical studies on *memory* have shown that chess players' performance is mediated by variables such as depth of processing, presentation time, typicality, level of randomization, and age (for reviews, see Holding, 1985; Saariluoma, 1995; or Gobet, 1998). Interestingly, and contrary to widely held opinion, masters' superiority is maintained with briefly-presented positions, even after their semantics have been destroyed by randomizing the location of pieces (Gobet & Simon, in press). While the effect is small, it is also reliable, and has been found in other domains of expertise such as programming and music.

As witnessed by the formidable time chess masters spend studying books and analyzing games, *knowledge* plays an important role in chess expertise. Several researchers have attempted to study knowledge directly, using techniques such as sorting experiments, questionnaires, and verbal reports. There is evidence that expertise correlates both with qualitative organization of knowledge and with quantitative amount of information stored (Freyhoff et al., 1992), reflecting findings of other domains of expertise, such as physics.

While De Groot's statistics about *problem solving* have in most cases withstood the test of time, subsequent research has identified a few skill differences. In particular, it has been found that depth of look-ahead search varies as a function of skill (e.g., Saariluoma, 1995), although the effect is rather small.

Several studies have addressed the question of whether *intelligence* correlates with chess skill. The general conclusion is that there is a correlation with tests measuring general intelligence, but not with tests measuring visuo-spatial intelligence (Doll & Mayer, 1987). From these studies, it is unclear whether chess practice develops aspects of intelligence measured in IQ tests (a good candidate explanation would be ability to think under time pressure), whether attainment of a high skill requires superior intelligence, or whether both intelligence and chess skill are causally related to a third variable, such as an ability to concentrate for long periods.

Finally, chess has been a useful domain for studying the cognitive processes that support outstanding skill in problem solving across the life span. In particular, chess has been useful in identifying compensatory mechanisms used by older adults to allow high-level performance in spite of age-related declines in perceptual, memory, and cognitive abilities (Charness, 1981).

## Theories of Problem Solving

Given the rich set of empirical data generated by chess research, it is not surprising that chess has produced several theories of expertise. It is convenient to present these theories as mainly addressing either problem solving or memory, although they often aim at a general characterization.

The first theory devoted primarily to problem-solving behavior in chess is De Groot's (1946) elaboration of Otto Selz's framework of productive thinking. Selz proposed that thinking is a continuous activity that can be described as a linear chain of operations. De Groot showed that this framework was, with a few extensions and modifications, quite successful in accounting for chess thinking. As anticipated by Selz, players often use a hierarchy of subsidiary methods, which relates to Newell and Simon's (1972) means-end analysis. For De Groot (1946) a necessary condition for becoming a chess master is the construction through experience of two things: a highly developed and specific mode of perception, and a system of reproductory methods stored in memory. Chess players' memory can be separated into *knowledge* (knowing that...) and *intuitive experience* (knowing how...).

Selz's description of thought as a sequence of operations is also apparent in the formal models developed by the Carnegie Mellon research group centered around Herbert Simon (this research is summarized in Newell & Simon, 1972). Two computer programs (written by Newell, Shaw & Simon in 1963, and by Baylor & Simon in 1966, respectively) implemented the idea of selective search made possible by the use of heuristics. Another model, developed by Newell and Simon in 1965, used the evaluation obtained at the end of a branch to formulate six principles that dictate the generation of moves and sequences of moves. Several of these ideas have been recently combined with the chunking theory (see below) in a probabilistic model of chess thinking (Gobet, 1997).

Two informal theories have also been influential in research on expertise. Holding's (1985) theory emphasizes the role of search and knowledge and suggests that human experts search in ways similar to computers. The theory discussed by Saariluoma (1995) proposes that players, while thinking about a position, access goal-positions by apperception—that is, conceptual perception. They then try to close the path between the problem position and the goal-position. When this is not possible, the problem space is restructured. Thus, chess thinking may be described as a sequence of apperception-restructuration cycles, which make it possible to find solutions with only limited search.

While these theories differ in their emphasis and in their specificity, going from formal computer programs to informal verbal theories, they also share a few important assumptions: they all emphasize the role of knowledge in problem solving and the high selectivity of human search.

## **Theories of Memory**

One can identify four major theories of chess perception and memory in chess expertise (Gobet, 1998). The most influential of them is Simon and Chase's (1973) *chunking theory*, which proposes that experts acquire a vast database of chunks (perceptual patterns that can be used as units) giving access to semantic memory and to procedural memory. Subsets of the chunking theory were implemented in 1973 in a computer program by Gilmartin and Simon. Based on extrapolations from the simulations, it was estimated that between 10,000 and 100,000 chunks are necessary to reach a high level of expertise. However, some weaknesses of chunking theory were uncovered by later research, mainly the fact that it underestimates storage into long-term memory (LTM), and that it underestimates the role of high-level structures such as schemata (Charness, 1976; Holding, 1985).

Several attempts have been made to repair these theoretical weaknesses, while still accounting for the data that chunking theory successfully explained. Holding (1985) is representative of a group of researchers emphasizing the role of high-level knowledge structures, such as schemata or prototypes. In opposition to the simple and specific structures proposed by Chase and Simon, Holding emphasizes that chess masters' memories are richly organized and general. Emphasis is also given to metaknowledge, which consists of principles for efficient search and evaluation of positions.

Ericsson and Kintsch's (1995) long-term working memory theory emphasizes that experts in various fields, including chess, can encode information into LTM more rapidly than had been postulated by traditional models of human memory. In the spirit of Selz and Newell and Simon's (1972) approaches, this theory views cognitive processes as a sequence of stable states representing end products of processing. Through acquired memory skills, these end products can be stored in LTM and can be accessed from short-term memory by means of retrieval cues. Two intertwined mechanisms allow rapid storage into LTM. The first mechanism allows encoding through a hierarchical retrieval structure; in the case of chess, the retrieval structure corresponds to the 64 squares of the board. The second mechanism allows encoding through knowledge-based associations that elaborate patterns and schemata stored in LTM. Ericsson and Kintsch suggest that these two mechanisms account for chess masters' excellent memory for chess material, as well as for their ability to plan and to evaluate alternative sequences of moves.

Gobet and Simon's (in press) template theory proposes that patterns recurring often in players' practice and study lead to the creation of more complex data structures, called templates. As with classical schemata, templates have both a core (containing the same information as chunks), and slots, where variable information can be stored. The template theory is implemented as a computer program, which acquires chunks in an unsupervised way by scanning a large database of master games. The program can simulate various data from perception, such as players' eye movements during the first five seconds of presentation of a position, and from memory, such as the role of presentation time on memory recall. A version of the program also plays (poorly) by pure pattern recognition.

One of the important challenges facing researchers in the field is to provide a coherent and integrated picture of chess thinking, combining simple perceptual structures such as Chase and Simon's chunks with more complex structures such as schemata. Long-term working memory and template theory can be seen as attempts to address this challenge.

## Future Lines of Research

Chess expertise has been extensively studied in the past (more research has been done in psychology about chess than about all other games put together), and it is likely that this will continue in the future. In most cases, results from chess research can be generalized to other domains of expertise. While scientific understanding of expertise has grown substantially through a large number of experiments and through a wealth of theoretical developments, there is still no single theory able both to account for most of the empirical data and to simulate human behavior by playing chess at a high-level of expertise. With the rapid progress in artificial intelligence and computer science, which have already produced grandmaster-level programs by brute force, it is however realistic to expect such a theory within a decade or two. In addition to this effort in computer modelling, a main research domain is likely to be neuropsychological investigation using brain imaging techniques to study the biological substrate of chess expertise.

(See also: Expert Memory, Psychology of; Short-Term Memory, Cognitive Psychology of; Working Memory, Psychology of; Protocol Analysis, in Psychology; Medical Expertise, Cognitive Psychology of; Physics Expertise, Cognitive Psychology of)

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