Cognitive Modeling of Knowledge-Guided Information Acquisition in Games

Reijer Grimbergen

Department of Informatics, Yamagata University, Yonezawa, Japan
grim@yz.yamagata-u.ac.jp

Abstract. Since Chase and Simon presented their influential paper on perception in chess in 1973, the use of chunks has become the subject of a number of studies into the cognitive behavior of human game players. However, the nature of chunks has remained elusive, and the reason for this lies in the lack of using a general cognitive theory to explain the nature of chunks. In this paper it will be argued that Marvin Minsky's *Society of Mind* theory is a good candidate for a cognitive theory to define chunks and to explain the relation between chunks and problem-solving tasks. To use Minsky's *Society of Mind* theory to model human cognitive behavior in games, we first need to understand more about the primitive agents dealing with the relation between perception and knowledge in memory. To investigate this relation, a reproduction experiment is performed in shogi showing that perception is guided by knowledge in long-term memory. From the results we may conclude that the primitive agents in a cognitive model for game-playing should represent abstract concepts such as *board*, *piece*, and *king* rather than the perceptual features of board and pieces.

1 Introduction

Game research has been a success story for the engineering approach, just like many other research areas in Artificial Intelligence. DEEP BLUE, probably the most famous of all game programs, searched between 100 million and 200 million positions per second in its 1997 match against Kasparov [3]. Human players clearly use a different approach, considering only a small number of positions per second and a small number of candidate moves (between 3 and 5) in any position [5].

In the past, there has been research by De Groot [5] into the behavior of chess players. Also well-known is the work by Chase and Simon [4], who introduced the idea of *chunking* of game knowledge to explain the difference between the performance of expert players and beginners in memory tasks. The nature of these chunks of game knowledge has been studied in other games such as Go [2,10], but there is not much known about chunks in games other than that they exist.

The most important reason for this omission is that there has never been an attempt to represent the essential game knowledge from the ground up. Without a proper understanding of how the most primitive building blocks of game

H.J. van den Herik et al. (Eds.): CG 2008, LNCS 5131, pp. 169–179, 2008.

knowledge interact to become chunks, it seems quite difficult to find the true nature of chunking. A general theory about human cognition is needed to define these building blocks and the interaction between them. Marvin Minsky's (1988) inspiring *Society of Mind* theory [9] is such a theory and our research aims at using Minsky's theory to simulate the chunking behavior of human game players.

In this paper the results of a reproduction experiment are given. They have important consequences for the content of the primitive agents and agencies dealing with input that are a vital part of a cognitive model for game-playing using Minsky's theory. Shogi (Japanese chess) will be used because we have performed earlier cognitive experiments in this game [6], but the results are general and do not depend on any shogi specific knowledge.

The rest of this paper is built up as follows. In Sect. 2 the theory behind the cognitive model for game-playing currently being built is explained. As a starting point, the primitive agents dealing with perception need to be defined. To investigate the nature of these primitive agents, in Sect. 3 a reproduction experiment will be described. The results of this experiment are given in Sect. 4. They show that perception in game playing is guided by game-specific knowledge and not by the perceptual features of the game. Finally, in Sect. 5 the conclusions and plans for future work are given.

2 A Cognitive Model for Perception in Games

To reproduce game positions, information about the positions must be stored in memory. Memory storage is often represented using the three-stage memory model proposed by Atkinson and Shiffrin [1]. This model states that human cognition is the result of the interaction between three different types of memory: sensory memory, short-term memory, and long-term memory (see Fig. 1). This three-way memory model is also the basis for the perception model for chess proposed by Simon and Chase [11], which will be partly followed.

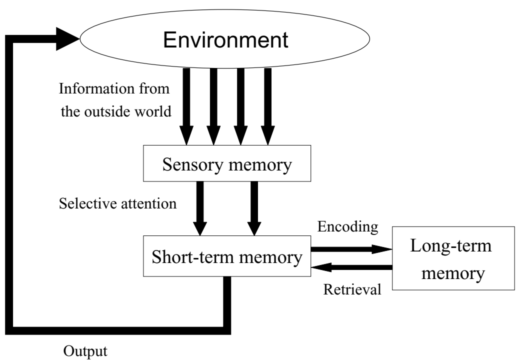

Fig. 1. Interaction between sensory memory, short-term memory, and long-term memory

Fig. 2. Perception guided by knowledge

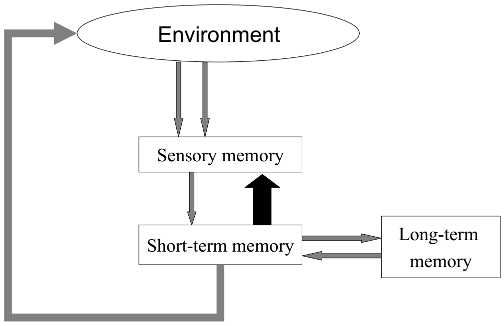

Fig. 3. Perception guided by knowledge in long-term memory

Sensory memory interacts with the environment by acquiring information through the senses. This is a subconscious process and therefore it cannot be guided. The amount of information that comes in through the senses is too high to process, so selective attention is used to limit the amount of information stored for further processing. This limited amount of storage is called short-term memory. Information in short-term memory can then be used to store and retrieve information from long-term memory or manipulate the environment.

Admittedly, this model of memory is too simplistic. However, it serves our modeling purposes except for one important extension. This is the phenomenon that we usually only see what we expect to see. For example, if we look at the picture of Fig. 2 for the first time, without any hints about what is in the picture, it is hard to see anything but a blur [7]. However, once we are told that the head of a cow is in the left side of the picture the blur changes into a cow. Furthermore, if we look at this picture again, we will find it very hard to “unsee” the cow.

The point of this example is to illustrate that perception seems to be guided by knowledge in long-term memory. Therefore, the actual three stage memory model used in our research is the one in Fig. 3, where knowledge from long-term memory is transferred to short-term memory. This information is often only confirmed using sensory memory. In the example above, it means that by our knowledge that there is a cow in the picture (long-term memory knowledge), we just need to check that it is really there. When using this model, the task of short-term memory is threefold: (1) gathering information, (2) guiding environment interaction, and (3) confirming information.

Next, we explain how to build a cognitive model for games using the three-stage memory model given in Fig. 3 by looking at the features of each type of memory in more detail.

2.1 Sensory Memory

For each sense, there is a specific kind of sensory memory, but in games we only need to consider *iconic memory*, which is sensory memory dealing with visual stimuli. When we look at something, we fixate the central part of the eye (called the *fovea*). Such a fixation lasts from 200ms to up to 500ms or longer and the information gathered by a fixation is stored in iconic memory.

Experiments by Sperling [12] showed that iconic memory is like a snapshot picture. Even though most information is gathered around the point of fixation, we also have access to information further away. To avoid having to deal with all this information at once, selective attention is used to transfer a limited amount of information to short-term memory, where it can be used for further processing.

The content of iconic memory in games has been studied in detail by Tichomirov and Poznyanskaya [13]. They tracked the eye movement of an expert chess player during the first five seconds of trying to find the best move in a given position. They established that in these 5 seconds there were about 20 eye fixations. Most of these fixations were on squares occupied by pieces that could be considered important for that position. There were almost no fixations at the edges or corners of the board and also almost no fixations on empty squares. Furthermore, the fixations moved between pieces that could be considered to have a relation.

2.2 Short-Term Memory

Sperling's experiments also showed that the capacity of short-term memory is limited. The amount of information that can be stored was already known, because in 1956 Miller famously put a number on it: "The Magical Number Seven, Plus or Minus Two" [8]. Miller also gave the unit of this capacity the name *chunk*. A chunk is a piece of meaningful information, i.e., information that has a relation to information in long-term memory. A chunk can be quite small, like a single letter, but can also be much bigger. For example, a string of letters representing the name of a friend can be handled as a single chunk in short-term memory. As explained before, short-term memory has three different functions. Therefore, short-term memory is overwritten often and it is hard to measure exactly how long its storage capacity is. Estimates differ from 2 seconds to more than a minute.

A well-known study into the nature of chunks in games is performed by Chase and Simon [4]. They repeated earlier work by De Groot [5] in which chess players of different playing strength were asked to reproduce chess positions after viewing them for 5 seconds. The important difference with De Groot's work was that they also provided random positions. There were big differences in the reconstruction ability of normal chess positions, but the reconstruction ability was almost the same for random positions. The conclusion was that the difference in reproduction was caused by the fact that stronger players have bigger chunks of chess knowledge, so it is easier to fit a position having many pieces into the limited storage capacity of short-term memory.

Therefore, short-term memory can be modeled as a string of seven codes or link addresses to knowledge in long-term memory. The knowledge in long-term memory that is represented by this code can be very complex. The observation was already recognized by Simon and Chase [11] and implemented in their perception model. They went on and tried to simulate the behavior of the experts players from the Tichomirov and Poznyanskaya's experiments. However, this behavior turned out too complex, illustrated by the low number of eye fixations, indicating that a large amount of cognitive processing was involved. As a result, the Simon and Chase model was able to simulate some of the behavior observed by Tichomirov and Poznyanskaya, but failed to come up with a general framework for human cognition in games. Rather than making a model that tries to explain this complex behavior, it is better to start with the most basic behavior that is the same for players of all playing strengths. Therefore, the research presented here will first look in detail at the perception of board and pieces.

2.3 Long-Term Memory: The Society of Mind

Iconic memory and short-term memory are relatively well-understood, but this is not the case for long-term memory. The only thing that is certain is that the information in long-term memory lasts for decades and that its storage capacity is big enough to last a lifetime. Chase and Simon used so-called *inter-piece interval times* to investigate the nature of chunks in chess, but the jump from these inter-piece interval times, which are the same for players of different playing strength and chunks which are supposed to explain the differences between players of different playing strength is not convincing. Therefore, instead of following Simon and Chase, the nature of chunks will be investigated from the ground up.

Our approach for modeling long-term memory in games is to start with the most primitive chunks using Marvin Minsky's *Society of Mind* theory [9]. Minsky sees the mind as a large number of specialized cognitive processes, each performing some type of function. The simplest type of cognitive process is performed by an *agent* and the term *agency* is used to describe societies of agents that perform more complex functions.

Minsky defines an agent as: "Any part or process of the mind that by itself is simple enough to understand" [9]. It is important to realize that the cognitive processing units in the brain need to be simple, in the order of agents recognizing color and shapes. Complicated behavior is the result of the interaction between groups of simple agents. Minsky describes a number of ways in which such an interaction can take place, the most important of which is the use of *K-lines*.

Minsky's theory is much more diverse than just agents, agencies, and K-lines. However, to use this theory for modeling game play, the first step is to understand the most primitive building blocks. Therefore, we first need to know about the agents that deal with input and output. The input for cognition in game-playing is perception of the board and pieces, while the output is playing moves. In the rest of this paper, it will be investigated how perceptual features of board and pieces influence the content of memory. Once we know this relation between perceptual features and cognition, the set of primitive agents can be decided. For example, if bigger pieces are more easily remembered than smaller pieces, we need an agency that can make a difference between pieces of different sizes.

To investigate the relation between perception and memory, a reproduction experiment has been carried out. This reproduction experiment will be described next.

3 Reproduction Experiment

To get a proper understanding of the fundamental agents dealing with perception, a reproduction experiment has been performed in the game of *shogi* (Japanese chess). Although the experiment has been done only for shogi, the same experiment can be done for any board game; the results are not expected to be game-specific. The main reason for this is that we made sure that no chunking was used. To achieve this, the reproduction experiment was performed using randomly generated shogi positions. Moreover, the subjects were all beginners at shogi, minimizing the amount of shogi-specific knowledge to guide perception using shogi chunks.

The experiment was designed to test the following four hypotheses.

Hypothesis 1: It is easier to perceive one's own pieces than the opponent's pieces. This hypothesis was based on the fact that in shogi (like in Chinese Chess), the name of the piece is written in Chinese characters on the piece. The Chinese characters of the opponent's pieces are thus seen upside down from the viewpoint of the player and might therefore be more difficult to perceive.

Hypothesis 2: It is easier to perceive promoted pieces than pieces that are not promoted. This hypothesis is based on the fact that the Chinese characters for promoted pieces are simpler than the characters for non-promoted pieces.

Hypothesis 3: Pieces closer to oneself are easier to perceive than pieces further away. This is the general perception principle of information about things near to oneself being more important than information about things that are further away.

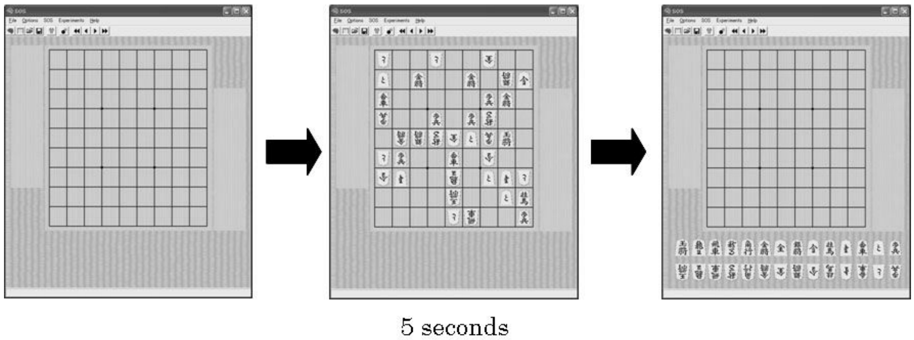

Fig. 4. Example of a position from the reproduction experiment

Hypothesis 4: Bigger pieces are easier to perceive than smaller pieces. This is also a general perception principle of bigger things being more important than smaller things.

The reproduction experiment to test these hypotheses was performed as follows (see Fig. 4). First, subjects were shown a shogi board without any pieces. When they felt ready to be shown the position, they pushed a button and a position would appear. This position would be shown for 5 seconds and then it would disappear, being replaced by an empty board with pieces lined up at the bottom of the screen. These pieces could then be moved to the board. There was no time limit for the reproduction phase of the positions. When the subjects felt that they had completed the task, they could click on a button and be shown the next position.

There were two positions used to explain the experiment and no data for these positions were recorded. In the experiment 10 randomly generated positions were used. The experiment is similar to the reproduction experiments we performed earlier [6], but with an important difference. The positions in our earlier experiments were generated by playing randomly from the starting position. Because of this, the generated position will have similarities with the well-known starting position, thus risking the use of chunks by the subjects.

We used 11 subjects in this experiment, all in their early twenties. Nine of the subjects had only a rudimentary knowledge of shogi, and two played a little more seriously in elementary school, but without ever gaining an official grade.

4 Experimental Results

Below, the results of the reproduction experiment related to the hypotheses will be presented.

Hypothesis 1: It is easier to perceive one's own pieces than the opponent's pieces. To test this hypothesis, data about the difference between the reproduction of own pieces (Chinese characters on the pieces displayed in the

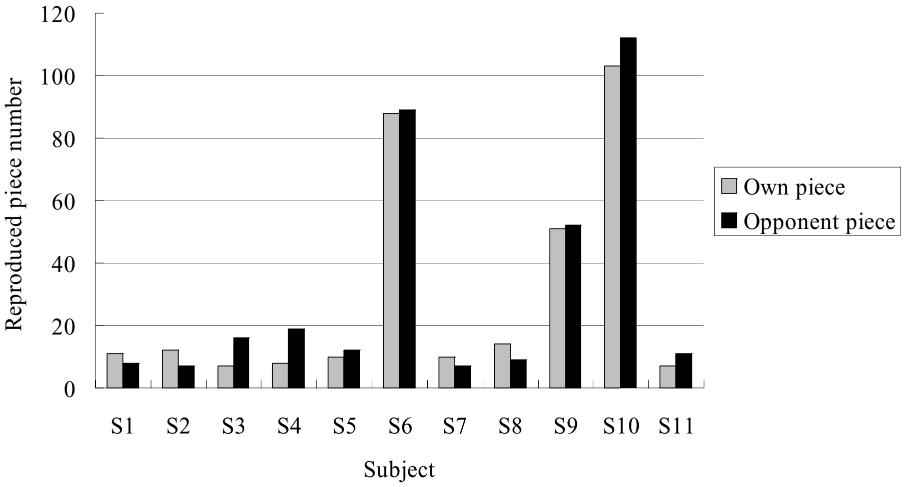

Fig. 5. Reproduction differences between own pieces and opponent pieces

normal way) and opponent pieces (Chinese characters displayed in reverse) was collected. The results are given in Fig. 5. From these results it can be concluded that in this experiment there was no data supporting the hypothesis. Only four subjects reproduced more of their own pieces than pieces of their opponent and only for subject S8 this difference seemed significant. Furthermore, the total number of own produced pieces was 321 (30.7%), while the total number of produced opponent pieces was 342 (31.7%).

Hypothesis 2: It is easier to perceive promoted pieces than pieces that are not promoted. To test this hypothesis, the difference between the reproduction of promoted pieces and non-promoted pieces was investigated. The results of this comparison are given in Fig. 6. From these results it can be concluded that non-promoted pieces are reproduced more than promoted pieces, so the hypothesis must be rejected. However, there are a number of subjects (S2, S3 and S11), who made an effort reproducing promoted pieces instead of non-promoted pieces. This did not lead to better performance regarding the correctness of the reproduced pieces, so this strategy seems to have no positive effect on memory storage.

Hypothesis 3: Pieces closer to oneself are easier to perceive than pieces further away. To test this hypothesis, a definition of *nearness* is needed. In the experiment, nearness is defined as the rank of the piece on which a piece is placed. The nearest pieces are therefore the pieces placed on the bottom rank, i.e., the rank closest to the player. Each rank further away is considered to be decreasing the nearness of the pieces. This assumption is consistent with the normal way of sitting behind a board. The results of piece reproduction according to this definition of nearness are given in Fig. 7. From this graph it is clear that there is no obvious relation between nearness and the reproduced

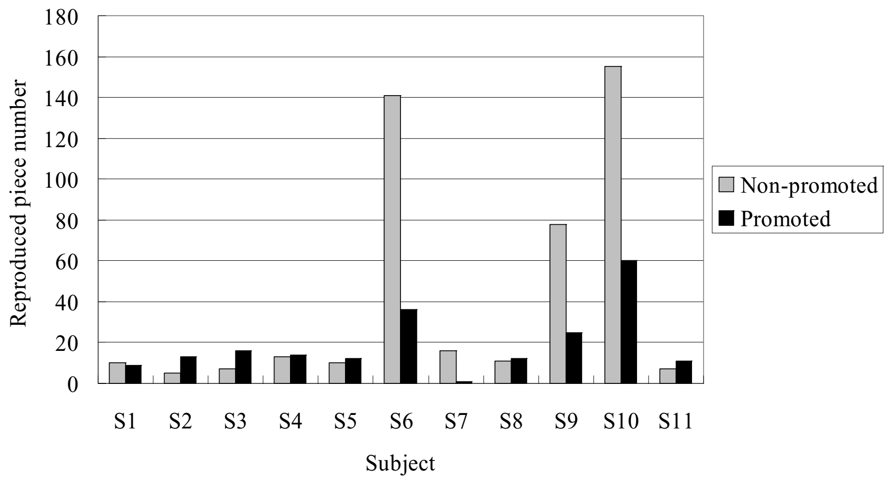

Fig. 6. Reproduction differences between promoted pieces and non-promoted pieces

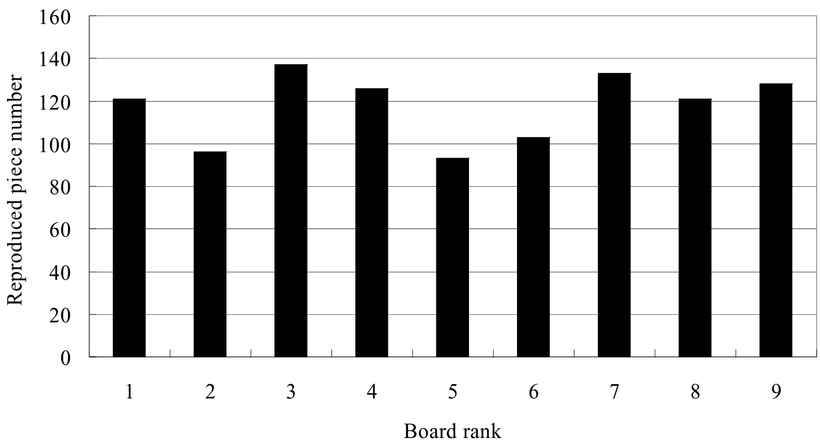

Fig. 7. Comparison of piece reproduction and nearness. Rank 1 represents the rank of the board closest to the subjects.

pieces and the hypothesis must therefore be rejected. In this case there was one subject who seemed to use a memorizing strategy where nearness played a role, but this subject reproduced pieces that were furthest away first, contradicting the assumption in the hypothesis.

Hypothesis 4: Bigger pieces are easier to perceive than smaller pieces. To test this hypothesis, data about the differences between the piece types of the reproduced pieces was collected. The standard relative size of each piece is given in Table 1. The pieces in the positions used in the experiment have the same relative piece size.

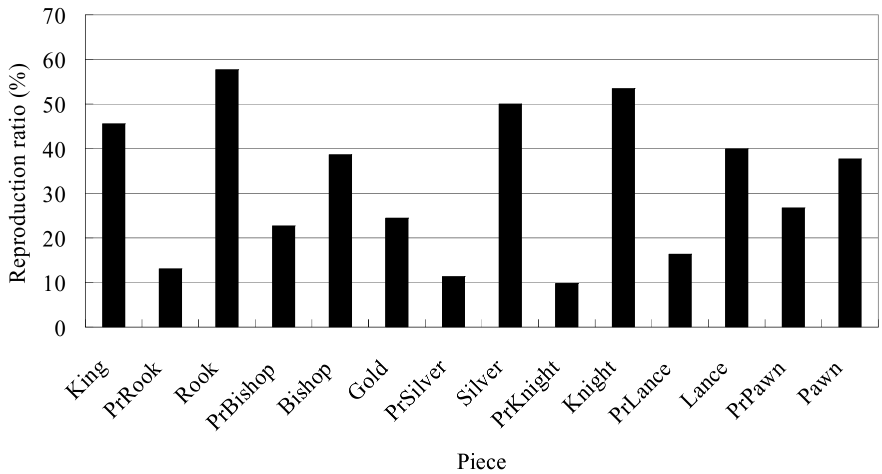

Fig. 8. Number of reproduced pieces for each piece type

Table 1. Piece sizes of shogi pieces in percentages relative to the size of the king. Note: promoted pieces have the same size as their non-promoted versions.

Piece	*RelSize*	*Piece*	*RelSize*
King	100	Silver	79
Rook	90	Knight	69
Bishop	90	Lance	59
Gold	79	Pawn	53

According to this table, the king should be reproduced more than the (promoted) rook and (promoted) bishop, which should in turn be reproduced more than gold and (promoted) silver, followed by (promoted) knight, (promoted) lance, and (promoted) pawn. The results of reproduction by piece type are given in Fig. 8. From this graph it may be concluded that there is no relation between reproduction ratio and piece size. Therefore, this hypothesis must also be rejected.

5 Conclusions and Future Work

In this paper it was explained why Marvin Minsky's Society of Mind theory is a good candidate for representing game-related knowledge in long-term memory. The goal of our research is to make a cognitive model for game-playing based on the Society of Mind theory. As a first step, in this paper a reproduction experiment was presented to get a proper understanding about the nature of the most primitive agents in the model, namely the agents that deal with the perception of board and pieces.

The experiment showed that perceptual clues in board and pieces (such as piece size) do not guide the knowledge stored in memory. This supports the assumption that perception is guided by knowledge in long-term memory and that perceptual clues are only used to trigger this knowledge. From these results we may conclude that the primitive agents in our model do not need to represent perceptual features directly. Rather, agents and agencies can be built around primitive concepts such as *board*, *piece*, *king* and so on.

The next step is now to define the primitive concepts in a game and build agents, agencies, and the K-lines between them to represent these primitive concepts. This will require further reproduction experiments using beginners where the task has to be changed from reproduction to finding the primitive concepts among non-related information. For example, finding the king in a randomly generated position. Also, the concepts (chunks) used by players of different playing strength need to be investigated in order to understand how agents and agencies develop over time.

References

1. Atkinson, R.C., Shiffrin, R.M.: Human memory: A proposed system and its control processes. In: Spence, K.W., Spence, J.T. (eds.) The psychology of learning and motivation: Advances in research and theory, vol. 2, pp. 89–195. Academic Press, New York (1968)
2. Burmeister, J.: Memory Performance of Master Go Players. In: van den Herik, H.J., Iida, H. (eds.) Games in AI Research, Van Spijk, Venlo, The Netherlands, pp. 271–286 (2000)
3. Campbell, M., Hoane Jr., A.J., Hsu, F.-h.: Deep Blue. Artificial Intelligence 134(1–2), 57–83 (2002)
4. Chase, W.G., Simon, H.A.: Perception in chess. Cognitive Psychology 4, 55–81 (1973)
5. De Groot, A.D.: Thought and Choice in Chess. Mouton & Co, The Hague (1965)
6. Ito,T., Matsubara H., Grimbergen R.: Cognitive Science Approach to Shogi Playing Processes (1) – Some Results on Memory Experiments. Journal of the Information Processing Society of Japan, 43(10), 2998–3011, (2002) (in Japanese)
7. McCracken, D., Wolfe, R.: User-Centered Website Development. Prentice-Hall, New Jersey (2004)
8. Miller, G.A.: The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. Psychological Review 63(2), 81–97 (1956)
9. Minsky, M.: The Society of Mind. Simon and Schuster, New York (1988)
10. Reitman, J.: Skilled perception in Go: Deducing memory structures from inter-response times. Cognitive Psychology 8(3), 336–356 (1976)
11. Simon, H.A., Chase, W.G.: Skill in Chess. American Scientist 61, 394–403 (1973)
12. Sperling, G.: The Information Available in Brief Visual Presentations. Psychological Monographs: General and Applied 74(11, Whole No. 498), 1–29 (1960)
13. Tichomirov, G.K., Poznyanskaya, E.D.: An investigation of visual search as a means of analyzing heuristics. Soviet Psychology, 5, 2–15 (Winter 1966-1967)