Memory Performance of Master Go Players

Jay Burmeister[α] and **Yasuki Saito**[β] and **Atsushi Yoshikawa**[β] and **Janet Wiles**[α]

[α] Schools of *Information Technology* and *Psychology*
The University of Queensland, Australia
[β] *NTT Basic Research Laboratories*
Atsugi, Kanagawa, Japan
jay@it.uq.edu.au

Abstract

Our overall goal is to study the use of information by Go players and the structure of their Go knowledge. In particular, in this paper we focus on human memory, and conclude with a discussion of the benefits of modelling human memory to AI and Go programs.

We report on two memory experiments. The first experiment used Japanese Go players to replicate earlier studies on Australian Go players. The second experiment consists of three case studies of master Go players (6 to 8 dan amateurs).

The general task in the experiments was to reconstruct Go positions stone by stone in correct game order. Two separate tasks were performed: in the episodic task, the moves from a Go game were shown to the subjects in a sequential presentation; in the inferential task, the subjects had to reconstruct Go positions with no information about how the game was played. In both tasks, feedback was provided after placement of each stone.

The first experiment replicated previous results for the experienced and beginner subjects. The case studies showed that extremely high levels of memory performance by the master subjects extended even to very fast presentation rates.

1 Introduction

Games such as chess have long been accepted as research domains in artificial intelligence (AI) and cognitive psychology because they can be formally specified and provide non-trivial domains without all the problems associated with real world complexity. In AI, chess has primarily been used to study tree-search, leading to the development of many search techniques such as minimax and alpha-beta pruning. In cognitive psychology, chess has been used as a means to study perception, pattern recognition, memory, encoding, and problem solving. Chess has also been used to: develop theories about the architecture of the human cognitive system; as a domain for cognitive modelling; as an empirical domain to study chunking; to study the nature of expertise in general and chess expertise in particular; and to contribute to an understanding of chess playing itself. Charness [1992] discusses the use of chess in cognitive science (i.e., the use of chess in AI and cognitive psychology), providing a comprehensive set of references.

Results from psychological research into chess have shown that chess players rely less on searching than on a thorough knowledge of chess patterns and an ability to access and use them effectively. Although this influenced some AI researchers to try to incorporate more knowledge into their chess playing systems, the performance of such systems did not keep pace with the performance of brute-force tree-search systems. The current state-of-the-art in brute-force chess programs, Deep Blue, beat the reigning world champion, Kasparov, in a best-of-six series this year. Chess programs play chess well but have ceased to make any contribution to the psychological understanding of human cognitive abilities and have also made a progressively diminishing impact on AI programming techniques as improvement to performance is now primarily achieved by speed improvements in hardware.

The game of Go has emerged as an appropriate successor to chess as a research domain for a variety of reasons. Go, like chess, provides a formally specified and non-trivial domain, however, Go is not amenable to brute-force AI techniques because there is no effective evaluation function available for Go programs. The current state-of-the-art in Go programs play at about the level of someone who has played a few games a week for a year and has studied some introductory Go books. Typically, Go programs try to limit the number of suggested moves to explore rather than prune the search tree as a result of an evaluation. The generation of good moves to examine requires the possession and effective use of Go knowledge. Thus, machines, just like humans, must rely more heavily on knowledge than on search to play Go well.

Unlike chess, the study of aspects of human knowledge within Go may well provide insights which lead to improved performance in Go programs. Of particular interest is the structure of knowledge possessed by human players since this may have an impact on the type of knowledge representation used in programs. One effective means for investigating human knowledge is through a memory testing paradigm.

Go in the Psychological Literature

Compared to the wealth of research into chess, there is little in the literature reporting either psychological or cognitive science research using Go as a domain. Reitman tried to replicate Chase and Simon's work on chunks in chess [Chase and Simon, 1973a; 1973b]. She found that unlike chess, chunks in Go are not organised either linearly or as nested hierarchies but as overlapping clusters [Reitman, 1976]. Eisenstadt and Kareev investigated the use of internal representations in problem solving using Go [Eisenstadt and Kareev, 1975]. They found evidence that familiar patterns are stored as an active procedural representation rather than as a static declarative representation. They also found that their subjects used both bottom-up and top-down search strategies when playing Go. Saito and Yoshikawa are developing a model of Go players' problem solving behaviour by collecting and analysing both verbal protocols and eye movement data [Saito and Yoshikawa, 1996]. Their analysis of verbal protocols showed that the use of language plays an important part in the selection of moves and that although verbalization causes players to play more slowly, it does not have a detrimental affect on their performance [Saito and Yoshikawa, 1995]. Saito and Yoshikawa [1997] provide a more comprehensive description of psychological and cognitive science research using Go as a domain.

Previous Work

In previous work, Burmeister and Wiles investigated the use of inferential information in remembering Go positions [Burmeister and Wiles, 1996]. The intention of the study was to demonstrate that contrary to the insignificant role attributed to inference in the pattern recognition and perceptual level explanations for chess memory performance advanced by de Groot [de Groot, 1965; 1966] and by Chase and Simon [Chase and Simon, 1973a; 1973b], inference may actually play an important role in memory performance. Inferential information was defined as new information inferred from existing information which consisted of the subjects' general Go knowledge and the feedback information provided during the reconstruction phase. Episodic information was defined as information related to episodes (or events); the simplest episode being the placement of an individual stone and more complex episodes being hierarchically constructed (e.g., opening or joseki sequences).

The subjects were given the task of indicating the sequences of between 17 and 35 moves (each being the placement of a black or white stone) from the opening (fuseki) moves of professional Go games. During reconstruction, the subjects received feedback information indicating whether their attempt was correct. Subjects could not progress onto the next stone until the previous one had been correctly reconstructed. After 10 unsuccessful attempts at reconstructing a stone, the stone would be placed for them. Two experiments were performed: assisted and cued reconstruction; in both experiments the subjects performed two tasks: episodic and inferential.

In the assisted reconstruction experiment, the subjects were assisted during the reconstruction phase by the stones being visible (and available for selection). In the episodic task, the stones were sequentially added every 2 seconds and the subjects then indicated the order in which they had been added. In the inferential task, the entire position was presented to the subjects and they were asked to infer the order in which the stones had been played.

In the cued reconstruction experiment, the subjects were not assisted during the reconstruction phase, having instead to select the board point where they thought the next move had been played. In the episodic task, the stones were added sequentially every 2 seconds as before, however, the reconstruction phase commenced with a blank board. In the inferential task, the first stone from a position was visible and the subjects had to infer where subsequent stones had been played.

The main source of information available in the episodic tasks was episodic information with inferential information being a secondary source of information. In the inferential tasks, the main source of information was inferential with no episodic information being available.

Australian experienced (10 to 1 kyu) and beginner Go players (25 to 15 kyu) were tested and the results showed that there was a facilitation for Go skill in both the episodic and inferential tasks and that cued reconstruction was more difficult than assisted reconstruction. It was also concluded that the use of inferential information may have a significant impact on memory performance.

Current Work

The aim of the current study was twofold. Firstly, to replicate, using Japanese players, the unassisted reconstruction experiment conducted in the Australian study [Burmeister and Wiles, 1996]. Secondly, an investigation of the performance of master subjects on the unassisted experiment, particularly their ability at fast presentation rates. The first author, in collaboration with the NTT authors, conducted the experiments detailed below at the NTT Basic Research Laboratories in Atsugi, Japan.

2 Unassisted Reconstruction by Japanese Players

The design of the first experiment was a replication of the unassisted reconstruction experiment conducted in our previous study [Burmeister and Wiles, 1996]. In the episodic task, the stones were presented in order every two seconds; in the inferential task, only the first stone was initially visible and the subjects had to select the point where they thought the next stone would be played.

It was expected that the results would be similar to our previous findings [Burmeister and Wiles, 1996] showing that there would be an effect for Go skill, that all subjects would perform better on the episodic task than on the inferential task, and that the subjects' performance on the inferential task would approach a significant proportion of their performance on the episodic task.

2.1 Method

Subjects

The 4 male subjects were paid university students. They were divided into 2 groups: experienced and beginner. The 2 experienced subjects were 1 dan and 3 dan and the 2 beginner subjects were both 17 kyu. The subject's ages were in the range of 19 to 23.

Materials

The board positions were selected from Go Seigen's[1] games rather than from Shusaku's[2] games which can appear unusual to experienced players because they are old fashioned. The Go Seigen games selected were considered to be more appropriate since they were contemporary in style. Eight board positions were selected in which there was a relatively even spread of stones around all the corners and edges and in which no stones had been captured. Each position contained 25 stones rather than 15 as for the previous study. Two practice board positions were used (one for the episodic task and one for the inferential task); the other 6 were randomly allocated into two sets of three (A and B).

The computer software specially written for the previous study was used to present the board positions to the subjects. Throughout the experiment, the subjects were seated in front of a colour X-window display (a monochrome X-window display was used in previous studies). A mouse was used to select stones during the reconstruction phase.

Procedure

Subjects were asked to complete the episodic and inferential tasks using the computer software described above. In the episodic task, the final position was cumulatively built by adding successive stones to the Go board on the computer monitor every 2 seconds in the order in which they had been played in the actual game. The board grid and stones were cleared for 10 seconds and then a blank Go board was displayed. The subjects were then asked to indicate where each stone had been played in the order in which they had been added to the board. Thus, during the reconstruction phase, the subjects were provided with no cues i.e., unassisted reconstruction was used.

The subjects selected a point on the board via the mouse and a stone of the correct colour was placed at that point. In the reconstruction phase, the subjects were asked to indicate where the stones had been played (i.e., added to the Go board on the monitor) in order. When an incorrect stone was placed (i.e., the point at which the stone was placed was wrong), an '×' was displayed in the middle of the stone. When a correct stone was selected, the number of the move on which it was played was displayed in the middle of the stone and any stones with an 'x' in them were cleared from the screen. If the subject could not correctly identify the next stone after 10 attempts, the computer would identify where the stone should have been placed and clear any incorrectly placed stones. In the inferential task, only the initial stone from the position was presented to the subject. The subject's task was to infer where subsequent stones in the game had been played and the mechanics of stone selection and feedback was also the same.

The subjects practised both tasks before testing. The presentation of the positions from sets A and B were counterbalanced for subjects within the experienced and the beginner groups i.e., one subject in each group received the set A positions in the episodic task and the set B positions in the inferential task and the other subject received the A and B sets in the reverse order.

2.2 Results

The percentages of stones correctly identified on each attempt (i.e., on the first, second, third etc. attempt) were plotted as a cumulative total for the episodic and inferential tasks for both the experienced and beginner subjects in Figure 1.

The results on the Japanese subjects were similar to those of the Australian subjects in previous studies [Burmeister and Wiles, 1996]. Subject's performance was related to Go skill and performance on the episodic task was better than on the inferential task for both the experienced and beginner subjects.

3 Master Players' Performance on the Unassisted Reconstruction Task

Since master subjects were not available to Burmeister and Wiles during their Australian study [Burmeister and Wiles, 1996], their performance on the unassisted reconstruction experiment was of particular interest. An appropriate level for the inter-stone delay was assumed to

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[1] A contemporary professional player whose career spanned the early to late 20th century.

[2] A famous professional player of the mid 19th century.

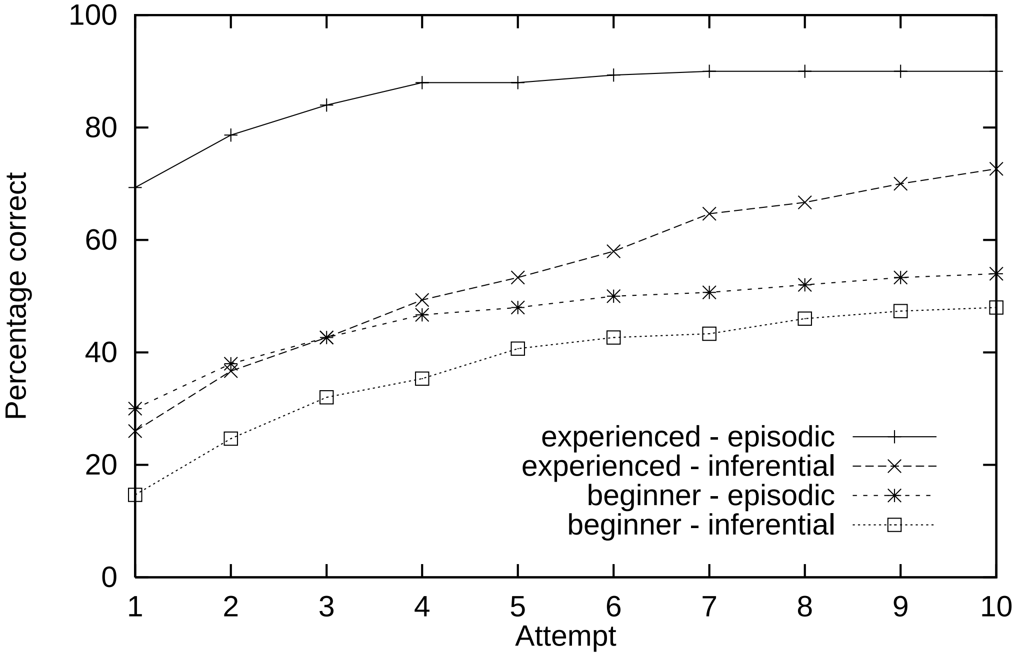

Figure 1: Experienced and beginner subjects' results. The cumulative percentage of correctly identified stones for each attempt for experienced and beginner subjects on the episodic and inferential tasks.

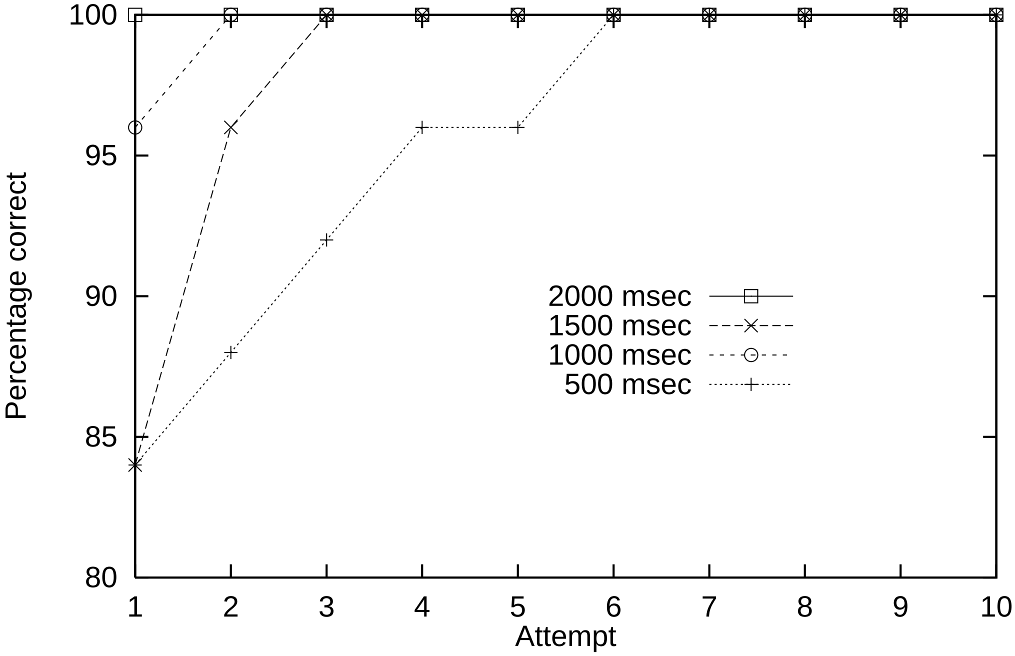

Figure 2: *8d* episodic trial results. The cumulative percentage of correctly identified stones for each attempt at 2000, 1500, 1000, and 500 milliseconds. (Note that only the y-axis starts at 80%).

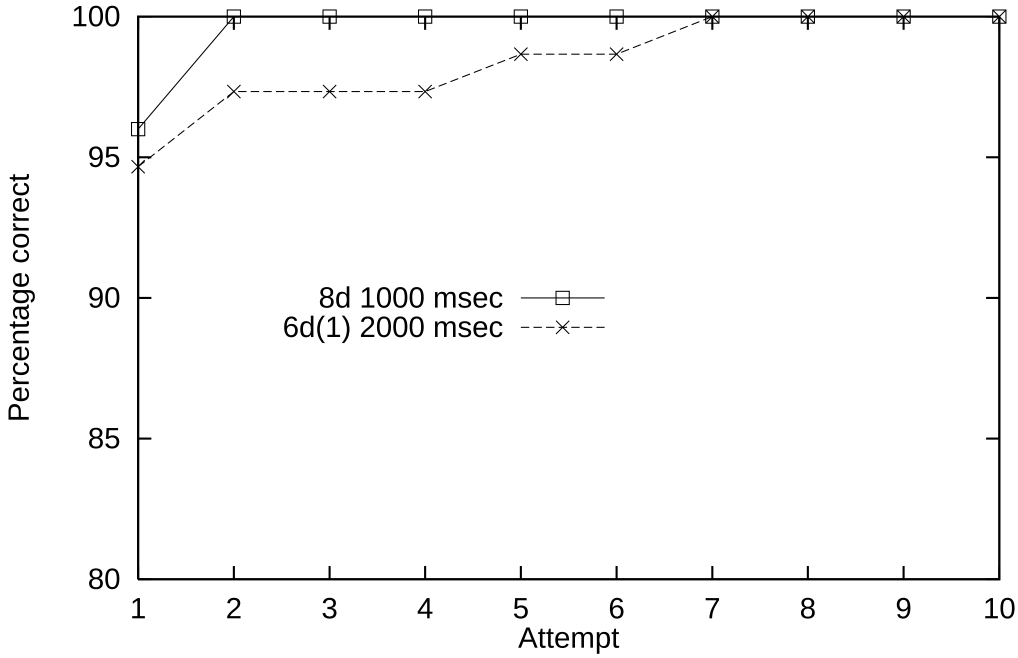

Figure 3: *8d* and *6d(1)* episodic results. The cumulative percentage of correctly identified stones for each attempt for *8d* and *6d(1)* tested at 1000 and 2000 milliseconds respectively. (Note that only the y-axis starts at 80%).

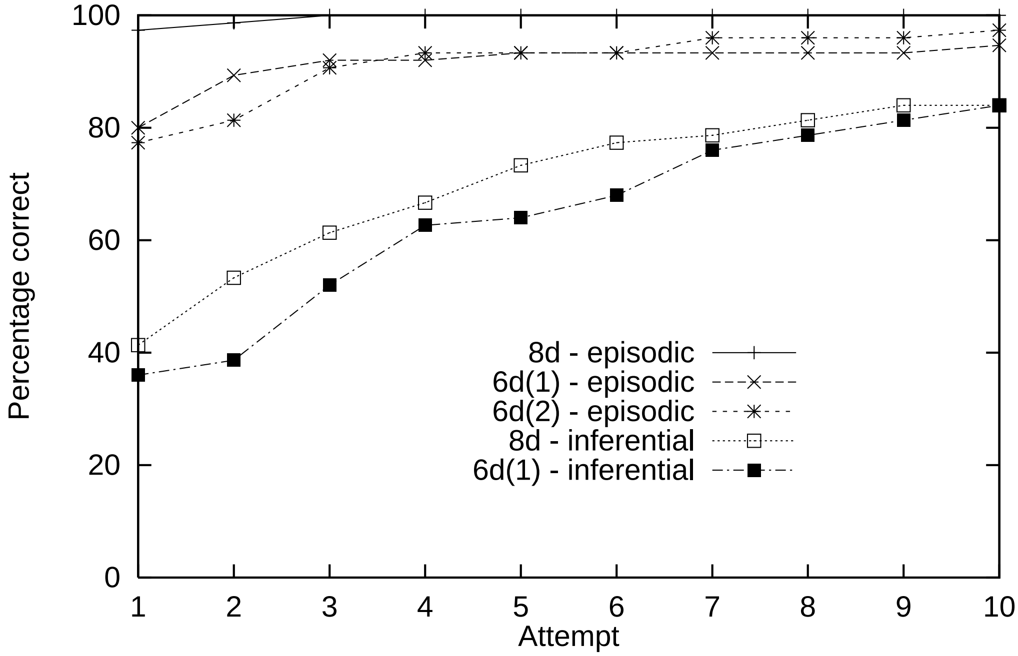

Figure 4: Master subjects' individual results. The cumulative percentage of correctly identified stones for each attempt for master subjects on the episodic (500 millisecond) and inferential tasks.

be lower than 2 seconds but was only a matter of speculation prior to actual testing.

Three case studies were conducted to investigate the performance of master subjects on the unassisted reconstruction experiment. We report both their performance and their relevant verbal reports.

3.1 Method

The methodology for the 3 case studies was similar to that used to test the experienced and beginner subjects in the previous experiment. Notable differences were in the delay between the stones and the boards used and will be detailed in each case study.

3.2 Case Study 1

In the first case study, the subject was a male 8 dan paid university student [3] and will be referred to as *8d*. Although an amateur, *8d* plays at around the level of a 1 dan professional.

Initial Test on Episodic Task

An initial test was conducted on *8d* to gauge the performance of a master subject on the episodic task at several different delay levels. Four 25 stone boards used in the previous study were used and *8d* was tested on a separate board at 2000, 1500, 1000, and 500 millisecond delays between stones. As can be seen in Figure 2, his performance was at ceiling with a 2000 millisecond delay and did not significantly drop until the delay was reduced to 500 milliseconds. His performance at 500 milliseconds was comparable with the performance of the experienced subjects at 2000 milliseconds although no stone required more than 6 attempts to be correctly identified. In general, his performance decreased as the delay decreased although his performance at the 1500 millisecond level was lower than at the 1 second level. This was most likely due to the difference between the individual boards. Due to the nature of the software used, delays lower than 500 milliseconds were not used.

Episodic Task at 1000 Millisecond

The next test was at 1000 millisecond delay between stones on the set A positions used to test the experienced and beginner subjects; the task was practised on 1 position prior to testing. Results are shown in Figure 3.

Episodic Task at 500 Milliseconds

The delay was decreased to 500 millisecond delay between stones on a new set (C) of 3 positions selected from Go Seigen's games using the same criteria as was used to select sets A and B; the task was practised on 1 position prior to testing. Results are shown in Figure 4.

Inferential Task

The inferential task was performed on the set B positions; the task was practised on 1 position prior to testing. Results are shown in Figure 4.

Verbal Reports

The subject reported that during the episodic task, he created a dialog of the 'story' as the moves were added to the board. Meaningful moves were remembered because they made sense in the context of the story. A few moves did not make sense with respect to the story and therefore stood out, making it easier to remember them. Although the subject was not explicitly asked, it would seem that the dialog he created indicates that there was an element of prediction associated with the next move. The nature of the prediction is likely to be the type of move (e.g., approach) and a general area (e.g., a small neighbourhood of points at which the move would be expected).

The subject commented that he would probably be able to replay the moves from the positions he was tested on up to 1 week later. Although his recall was not tested, his claim was consistent with his ability to remember entire Go games.

An interesting incident occurred during testing on a position in the episodic task at the 1 second delay. The subject was surprised by move 18 during the sequential presentation (which is consistent with the prediction hypothesis described above). During reconstruction, he made a mistake in placing move 16 but placed moves 17, 18, and 19 correctly. It seems that the surprise he experienced when move 18 was presented interfered with his encoding of the previous white move (move 16) rather than interfering with the encoding of subsequent moves.

There was a significant lag in the updating of graphic information during the reconstruction phase of the inferential task. The subject at times selected up to 15 moves without any feedback from the software with almost perfect results.

During the initial testing on the episodic task, the subject commented that he could 'image' the whole board between stones for all delays but could not do so at the 500 millisecond delay level.

3.3 Case Study 2

In the second case study, the subject was a female 6 dan paid postgraduate university student [4] and will be referred to as *6d(1)*. The 500 millisecond episodic task was identical to case study 1; the A and B sets were counterbalanced with case study 1 for the 2000 millisecond episodic task and the inferential task.

Episodic Task at 2000 Milliseconds

The 2000 millisecond episodic task was performed on the set B positions; the task was practised on 1 position prior to testing. Results are shown in Figure 3.

Episodic Task at 500 Milliseconds

The 500 millisecond episodic task was performed on the set C positions; the task was practised on 1 position prior to testing. Results are shown in Figure 4.

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[3] The subject received the 1997 university Meijin prize.

[4] The subject was the 1995 University Female champion.

Inferential Task

The inferential task was performed on the set A positions; the task was practised on 1 position prior to testing. Results are shown in Figure 4.

Verbal Reports

When tested at the 2000 millisecond delay level on the episodic task, the subject commented that she looked at the whole board between moves. She further indicated that joseki patterns were easy to remember and that tenuki moves did not present any problems either.

As for *8d*, *6d(1)* selected many moves without feedback during the reconstruction phase of the inferential task.

3.4 Case Study 3

In the third case study, the subject was a male 6 dan paid university student and will be referred to as *6d(2)*. The 500 millisecond episodic task was identical to case studies 1 and 2.

Episodic Task at 500 Milliseconds

The 500 millisecond episodic task was performed on the set C positions; the task was practised on 1 position prior to testing. Results are shown in Figure 4.

Verbal Reports

The subject commented that in the episodic task, he remembered the meaning of the moves (what the players were thinking). He indicated that joseki and shape were used to facilitate memory and that without such a strategy the short time between the stones would make remembering the moves difficult. He also reported that he remembered both the joseki and the direction which he described as 'economic thinking'.

4 Discussion and Conclusions

The tremendous memory ability of master Go players is possible, at least in part, to their use of meaning to remember moves encoded intrinsically in high-dimension vectors. This ability would indicate that the meaning of moves is an integral part of the Go representation they use during play.

The first experiment provided a clear replication of the results of the Australian study. Furthermore, the replication appears to be quite robust since it was obtained not only on a different set of subjects, but also using a different set of Go positions (i.e., Go Seigen games rather than Shusaku games). Although the case studies showed that master players' performance on the episodic task is affected by the speed of presentation, their performance remained at or near ceiling even at the 500 millisecond level. From the verbal reports provided by the master players, it seems apparent that the meaning of the moves is an important factor in memory performance.

It is common after teaching games for strong amateur and professional Japanese Go players to explore alternative sequences in order to learn how to play better. The exploration of alternative sequences does not usually interfere with their ability to reconstruct the original sequence. Whilst replaying games played against extremely weak players, some of the moves are described as difficult to remember because they 'have no meaning'. This description is perhaps similar in theme to Chase and Simon's finding that novice and expert chess players performed similarly on memory experiments using random chess positions [Chase and Simon, 1973a; 1973b]. As noted by Saito and Yoshikawa [1995], language descriptions are used to reduce the search space complexity. It seems likely that when the meaning of a move is not available, the search space is more spatial in nature and therefore larger with a resulting decrease in performance.

This is an interim report of the results, and raises as many questions as it answers. Further development of our experimental apparatus is required to enable the exploration of the minimum time required for the master players to encode the meaning of moves. It may also be possible, by employing eye camera techniques, to track the placement of stones in order to determine whether the limiting factor is visual perception or the encoding of the meaning of the moves. The dimensions of an expert's intrinsic representation may be revealed through analysis of the errors which may be elicited under further controlled studies.

5 What can AI Learn from Modelling Human Memory?

It is reasonable to ask how Go programs can benefit from experimental studies of human Go players. At this stage of our research, our answer is to point to general benefits and indicate potential in some specific areas: The cognitive sciences (including linguistics and psychology) have contributed to AI and Computer Science theory in many areas. Examples include automata theory and parsing processes (initially developed by Chomsky to account for human languages), list-processing languages (thought to reflect the list-like data structures of human thought), and artificial neural networks (initially inspired by the networks of neurons in the brain). The potential is there for AI to learn from human memory, which is still the most powerful system (natural or artificial) for the storage and later use of information. Some human memory properties are used in data structures (such as lists and trees), but many are not yet understood in a way that can be encoded as algorithmic data structures.

Human memory research investigates properties of the different memory systems, from transient short term effects to long term retention over years. It includes investigation of the representations of items for storage, their subsequent transformations and the multitude of access processes available to humans. The link between experimental research into the microstructure of human memory, and building better Go programs is not a direct one, but we see it as an important long term research strategy in developing more powerful data structures and algorithms based on cognitive processes.

From an AI programmers perspective, human memory is the file server of the cognitive system. However, unlike a computer's file server, human memory has computational properties for which there are as yet no known data structures in AI. The study of human memory holds the promise of discovering how Go experts represent information about a game, such as the board itself, and lexical and pattern knowledge. Studying human memory with respect to Go has two potential areas of benefit: *A*. It provides a methodology for investigating the abilities (and limits) of expert performance, and the memory systems that serve it; and *B*. It provides a testbed for theories of data structures and processes that are used in memory.

A. Human Memory: Experiments

The experimental results in this paper and in previous work [Burmeister and Wiles, 1996] are part of an overall project to investigate how different sources of information are used in Go playing, both during studying a board (i.e., memory storage) and during reconstruction (i.e., memory retrieval). Part of the information is provided inferentially (as shown by the inferential task in the unassisted experiments) and part is provided the episodic events.

Issues to be investigated in further studies include the nature of the inferential information, including volitional processes like reading (lookahead) and implicit processes such as pattern recognition.

B. Human Memory: Theory

Human memory is typically divided into three phases: acquisition, retention and retrieval. In the acquisition phase, a representation is formed, and is active in working memory (a short term process). Retention refers to the period between acquisition and retrieval, in which several processes may be active, from rehearsing the information, to transfer to long term memory. In the human memory literature (e.g., [Humphreys *et al.*, 1989]), several different types of retrieval processes are discussed, depending on the nature of the cuing process. The nature of data structures and cuing processes used in memory models depends on the theoretical framework of the modeller: opposing views are given by the symbolic and subsymbolic paradigms.

The symbolic view of memory is based on the computer analogy of registers or "pigeonholes". Information is represented symbolically, is local and addressable, and is amenable to search. All information regarding items and relationships between items is explicitly represented (e.g., in production rules, or explicit links in a semantic network). Memory processes are concerned with managing the items using structured storage and search processes. Although this view of memory is common in AI applications and high level cognitive models, it is not shared by human memory researchers.

The subsymbolic view of memory is based on representing knowledge as high-dimensional vectors of features in a vector space (i.e., representing knowledge intrinsically). The relationships between items can be represented explicitly as associations between vectors (i.e., extrinsically), but within a given domain, the relationships are intrinsic to the representation itself, i.e., the subsymbolic relationships are not open to inspection. Hence, information about items can be extrinsic (as explicit associations between items) or intrinsic (in the representation of an item itself).

In trying to develop a Go program, this has both advantages and disadvantages. An advantage of using a subsymbolic representation is that relationships between items are perceived seemingly directly, without mediation. A limitation of using a subsymbolic representation is that the intrinsic knowledge is only as powerful as the richness of the underlying vector space, and the accuracy of items within it.

From a subsymbolic perspective, we think that human expert players develop both intrinsic and extrinsic representational structures, whereas beginners possess an almost totally extrinsic representational structure. In modelling an expert's memory, items would be represented as high-dimensional vectors: major components of expertise involve knowing the dimensions of the space and the precise location of items in the the space (other aspects of expertise, e.g., lookahead, are also important as they provide a vehicle to apply the knowledge contained in the high-dimension representations). An expert's knowledge would include the space of possible moves, richness in the meaning of moves, lexical labels (e.g., form, position, contents, meaning, evaluation, judgement, plan, strategy).

Summary

As indicated at the start of this section, we feel that the general benefits of studying human memory lie in first demonstrating and then understanding the phenomenal abilities of expert Go players. This paper shows that experts can extract significant information in less than 500 milliseconds per move. In the previous section, we pointed to the potential for human memory to inspire novel data structures for storage and retrieval of Go knowledge. In particular, we referred to the human memory theory based on distributed representations. These ideas are as yet at a preliminary stage, but we feel that the power of human memory justifies our research program into human memory for Go and the data structures that underlie it.

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