Building the Society of Games

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Abstract: Studying the mind of human game players not only might lead to building intelligent machines, it could also be important for entertainment by creating more interesting computer opponents. In this paper I will present some ideas about how to implement Marvin Minsky's *Society of Mind* theory in a game-playing domain, specifically board games. The following concepts play an important role in Minsky's theory: agents, K-lines, polynomes, frames, difference-engines, censors and suppressors, A-brains and B-brains, connection lines and types of learning. In this paper, ideas are presented about how to link these concepts to concepts in games.

1. Introduction

Games are a multi-billion industry that is only growing, and the for the entertainment industry games are now at least as important as movies. It is expected that as far as entertainment in the summer of 2007 is concerned, the new Xbox game "Halo 3" will have higher revenues than the blockbuster movie "Spiderman 3". However, even though games amuse millions of people, it remains unclear why people are amused by games. What is going on in the mind of the game player?

There was a time when Artificial Intelligence embraced games as a constrained environment perfect for studying the workings of the human mind. But this line of research has been all but abandoned because when given a choice between having a relatively weak playing program based on sound cognitive modeling and a strong program based on engineering skills, most researchers have chosen to make strong game-playing programs. For example, the Deep Blue chess machine, which beat World Champion Gary Kasparov in 1997, examined 200,000,000 positions per second. On the other hand, cognitive research suggests that at the same time Kasparov probably looked at about 3 positions per second. This shows the huge gap between what computers do and humans do in a game-playing environment.

It is our belief that it is important to study the mind of game players. In the long term this will connect to the original goal of Artificial Intelligence to build truly intelligent machines. In the short term, studying the human mind during games could help in reaching one of the ultimate goals of the gaming industry: designing games that stay interesting. The reason why on-line gaming is so popular is simple: computer opponents in any game are boring after a while. One of the problems is predictability, but the general complaint is that there is no "human feel" to an AI opponent. The term "AI opponent" is a gross exaggeration of what these computer created characters can do.

This paper will not be about improving the entertainment value of games by creating interesting computer opponents. Without a proper understanding of how the mind of the human game player works, it is impossible to create a computer avatar that will seem truly human. Our objective is more general: to model human game playing using a sound theory about human cognition.

There are many cognitive theories about partial human behavior, but only a few have tackled the problem of the general workings of the human mind. An exception is Marvin Minsky's inspiring *Society of Mind* (Minsky, 1988) theory, which presents a general theory about the workings of the human mind. Minsky sees the mind as a large number of specialized cognitive processes, each performing some type of function. The most simple 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.

Despite the popularity of Minsky's book, there seem to have been few attempts to implement his theory. One difficulty is that Minsky presents his theory in a large number of small chapters, each dealing with a small part of the theory and at a variety of levels. Furthermore, the theory is so diverse that it seems difficult to apply to real-world problems. Real-world problems require the implementation of a large number of agents to represent common sense knowledge. Only after this, it is possible to think of agents and agencies that deal with the problem itself. Therefore, many researchers have considered the theory to be just a metaphor for human thinking, but we believe that it is more than that and that implementation of Minsky's ideas is possible. However, it is clear that applying the theory to real-world problems will involve all kinds of implementation issues with the vast number of necessary agents being one of the most important bottle-necks. This is where games can help out.

The problem of applying a new theory to a real-world situation has been an issue in Artificial Intelligence for a long time. A common idea is to first apply the theory to a simplified problem. Games and puzzles have been used as a test bed for AI theories in the past and it seems a good idea to use a game as a test domain for Minsky's theory of human cognition. In this paper, it will be explained how Minsky's theory might be implemented for games.

In Section 2, the important concepts of Minsky's theory will be explained. In Section 3 it will be explained how these concepts can be interpreted in the domain of a game. To build a *Society of Games*, three agencies need to be implemented: a *recognition agency*, a *look-ahead agency* and a *learning agency*. Ideas for implementing these three agencies for classic board games will be given in Section 4. Finally, in Section 5 the conclusions will be given.

2. The Society of Mind

As pointed out in the introduction, Minsky's *Society of Mind* is presented as a large number of small chapters, each highlighting a fraction of the theory. This is a very inspiring read, as each chapter seems to give some precious insight into the workings of the human mind. As an unfortunate side-effect, after finishing the book, it feels like one is ready to go, but it is hard to decide where to start. Therefore, instead of using Minsky's original text, in this section I will mainly use the outline of Push Singh (Singh, 2003), who gives an explanation of the important concepts of Minsky's theory. The main parts of the theory are *agents*, *agencies*, *problem solving*, *communication* and *growth*. These will now be explained in detail.

2.1. Agents

Minsky defines an agent as: “Any part or process of the mind that by itself is simple enough to understand” (Minsky, 1988). 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. The term "agent" seems to imply a more complex entity[1], but its processing capabilities are similar to that of small groups of neurons in the brain. 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: *K-lines*, *nemes* and *nomes*.

K-lines are used to turn on a particular set of agents. Agents can have many connections, so activating a K-line can lead to an avalanche of activations of other agents. A K-line reactivates a previous mental state based on similarities between the current situation and a situation previously encountered. “K-lines cause a Society of Mind to enter a particular remembered configuration of agents, one that formed a useful society in the past” (Singh, 2003).

One class of K-lines described by Minsky are *polynemes*, which invoke partial states in multiple agencies, where each agency is concerned with representing some different aspect of a thing. For example, seeing an apple arouses an ‘apple polyneme’ that invokes properties in the color agency (‘red’), shape agency (‘roundish’), taste agency (‘delicious’), cost agency (‘100 Yen’) and so on (Fig. 1).

It is important that ‘understanding’ is not done with a single representation, but distributed among a large number of property agencies.

2.2. Agencies

The description in Section 2.1. is about activating agents and agencies, but does not address the problem of how to combine simple agents into larger agencies that can do more complex things. Minsky uses *frames* as a way to construct agencies. Frames are a form of knowledge representation concerned with representing a thing and all the other things or properties that relate to it in a certain way.

A thing can be described by using a collection of frames where each frame describes the thing from a certain perspective. *Frame-arrays* are collections of frames that have slots in common. By sharing slots, it is possible to switch to a different frame if the initial frame is inadequate for solving some problem or representing some situation.

[1] In his new book *The Emotion Machine* (Minsky, 2006) Minsky himself admits that using the term "agent" was a mistake and instead proposes to adopt the word *resource*.

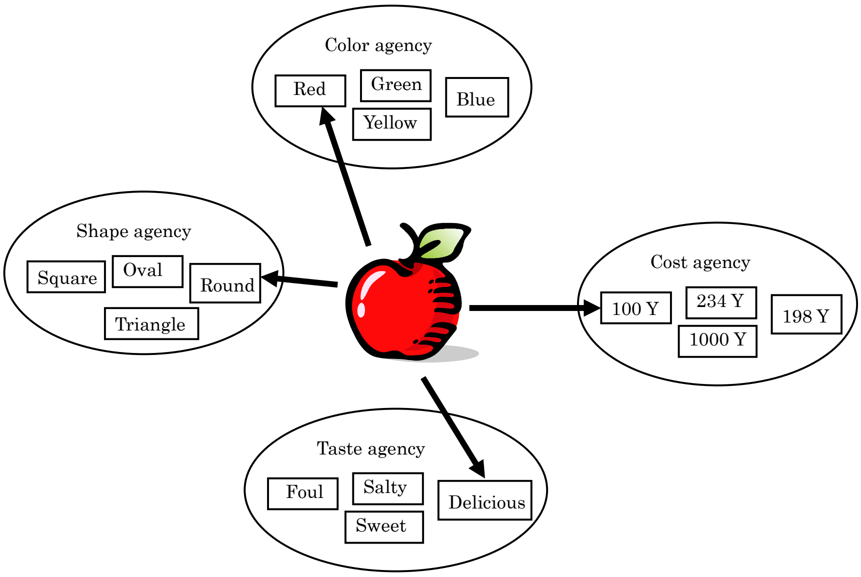

Figure 1: Small part of an apple polyneme

2.3. Problem Solving

Minsky argues that there may be many different methods that societies of agents use to solve problems. He suggests the following ways to organize problem solving societies: *difference-engines*, *censors and suppressors* and *A-brains and B-brains*.

Difference-engines are used to reduce or eliminate the important differences between the current state and some desired state. First, the differences between the current state and desired state need to be recognized. Then K-lines can be used to reduce each difference by invoking suitable solution methods.

No method of problem solving will always work, so in addition to knowledge about problem solving methods, we also have much knowledge about how to avoid the most common bugs and pitfalls with those methods. Minsky calls this *negative expertise*.

During the problem solving process, this is embodied in the form of censor and suppressor agents. Censors suppress the mental activity that precede unproductive or dangerous actions, while suppressors suppress those unproductive or dangerous actions themselves.

Some types of unproductive mental activity are not specific to any particular method, such as ‘looping’. Minsky uses the notion of the ‘B-brain’ whose job is not to think about the outside world, but rather to think about the world inside the mind (the ‘A-brain’). In this way, the B-brain can notice the errors and correct them.

2.4. Communication

Agents are very simple processes that need to interact to generate complex behavior. However, because they are so simple, agents know only very little about how other agents work, so communication between agents can only be on a very simple level.

Two important ways in which agents can communicate are *K-lines* and *connection lines*.

The K-lines we have explained before are the most simple way of communication between agents: just arouse some other set of agents.

Many agents are not directly connected to each other but rather communicate via connection lines, buses or bundles of wires that transmit signals to other agents attached to the bus. These wires can be initially meaningless, but over time the individual wires begin to take on local significance, that is, they come to acquire dependable and repeatable ‘meanings’.

2.5. Growth

Growth is very important in the society of mind. Mental societies are constructed over time and Minsky suggests that the trajectory of this process differs from person to person. He offers several potential mechanisms for growth.

In an infant mind, the first functional large-scale agencies are *protospecialists*. Protospecialists are highly evolved agencies that produce behaviors providing initial solutions to problems like locomotion, obtaining food and water and the like.

Predestined learning is the idea that complex behavior need not be fully pre-specified nor fully learned, but can result from a mixture of partial influences. Learning a language is an example of predestined learning, learning that develops enough internal and external constraints to more or less guarantee the final result.

Learning can take on different forms. For example, *accumulating* is remembering each example or experience as a separate case. *Uniframing* amounts to finding a general description that subsumes multiple examples. *Transframing* is forming an analogy or some other form of bridge between two representations. *Reformulation* is about finding new ways to describe existing knowledge.

An important type of learning is not so much about how to require the specific representations and processes needed to achieve some goal, but rather how to learn when a particular goal should be adopted and how it should be prioritized relative to other goals. Minsky suggests that we learn many of our goals through interactions with our 'attachment figures', special people in our lives, such as our parents, whom we respect. Praise and censure from our attachment figures result in 'goal learning' as opposed to 'skill learning'.

As an overall learning scheme, the mind needs to develop in multiple stages where these stages can be regarded as training each other. The mind can be seen as the result of a sequence of teaching operations where at each stage there is a 'teacher' that teaches the 'student'. At the next stage, the student becomes the teacher, and so on.

3. The Society of Games

Playing games is a problem solving task and therefore the general concepts of the Society of Mind theory that were described in the previous section will correspond to concepts in games. In this section the connection between general cognitive concepts and concepts in a game-playing environment will be presented.

3.1. Game Agents

The first thing that needs to be decided is what the primitive agents are in a game-playing domain. The most primitive agents in any domain are the agents concerned with input (perception) and output (action). In games, this would be agents concerned with recognizing the state of the game (input) and knowing what the possible actions are according to the rules of the game (output). These agents are initialized before the game is started and updated as the games develops.

Starting from this, the most simple K-lines are the K-lines that changes the internal representation of game situation and the K-lines that update the actions that can be performed based on the changed situation after a game action.

Polynemes are used to combine these primitive concepts into larger structures of patterns that are important for playing the game. For example, a key could be a concept connected to opening a door or a chest, be of some material (lead, bronze, gold), have a certain size and so on.

3.2. Game Agencies

Using frames to construct agencies can be effective in games as well. For example, an *encounter* frame could have slots for recognizing who the encounter is with, what to do if the opponent must be fought with, what to do in case of chatting or negotiating and so on. Frame-arrays could for example be used to connect knowledge of fighting with the use of weapons (Fig. 2).

Note that all the arrows in the figure have two directions, indicating the importance of feedback between different agencies.

3.3. Problem Solving in Games

For problem solving in games, difference-engines are important. Good game players are able to move into desired positions in a flexible way, without rigidly following the same action sequences.

Difference-engines might be easier to build in games than in other domains because location and action are the only basic representations.

Censors and suppressors are also important in games. Good game players do not discard bad actions, they are unable to see them. The most common errors by proficient game players are not thinking about bad looking actions that are actually good or overlooking bad looking actions by the opponent that are actually good.

The difference between A-brains and B-brains can also play an important role in games. Losing time by doing superfluous actions and returning to the same game situation are examples of problems

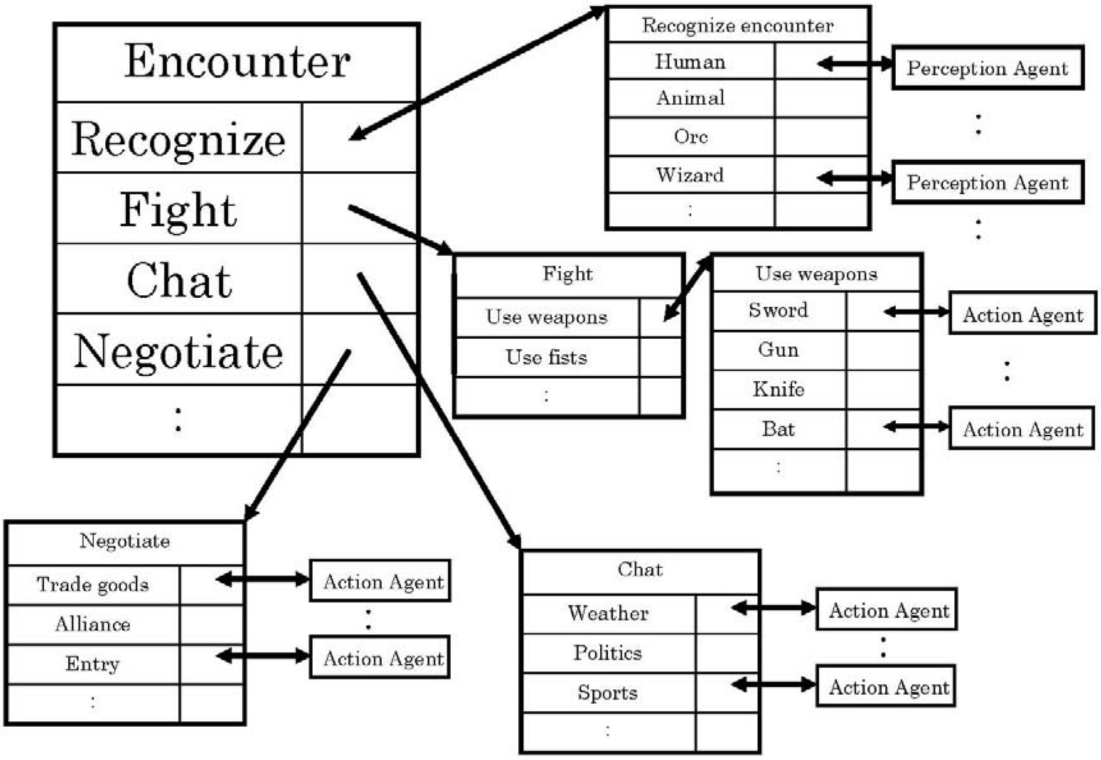

Figure 2: Example of a partial frame system for games.

that can be eliminated by using a B-brain to monitor the activity of the problem solving process.

3.4. Communication in Games

The importance of K-lines for communication between agents has already been discussed in Section 3.1. which leaves the communication using connection lines.

Connection lines are a way to control signals between different agencies and without implementing those agencies there is not much that can be said about them. It is believed that these connection lines can be used to control the *activation level* of agents. Minsky's theory is unclear about this, but I think that activation level is an important control mechanism to make a difference between important and less important concepts during problem solving. For example, when one is weakened during a fight, it is better to start looking for food than continuing with the main mission. Both goals should be active, but the priority of the goals changes based on the game situation.

3.5. Growth in Games

Learning is of course very important in any society of agents. In games there doesn't seem to be much use for protospecialists and predestined learning. These types of learning mainly seem to be involved with learning how to play the game. They might become important when a society of agents is built that can learn to play any game given a description of the rules.

Accumulating in games could be the storage in long-term memory of every game situation that has occurred in the past. It is well-known that top game players can remember the games they played for a very long time. Uniframing can be used to categorize a certain game (for example, a shooting game, RPG, etc.). Transframing might be used to learn concepts like using the same weapon in different situations. An example of reformulation is changing enemies into allies by making an alliance.

To guide learning, the role of attachment figures is also important in games. Rather than one's parents like in most learning situations, the attachment figures in games are the top players.

4. Building Shogi Agencies

The next step is to build the Society of Games based on the ideas outlined above. Even though the examples were about general games, we feel that most of the current video games are still too complex and too close to the real world to benefit from the simplification that a game environment provides. Therefore, before moving to games with a complex game playing environment, we will first try our approach in a number of classic board game like chess, shogi and Go.

The number of possible actions and possible perceptions in a chess-like board game is very limited, which will limit the number of primitive agents that need to be defined. This will also limit the number of agencies. Once we have a Society of Games for board games, we can move on to more complex games, aiming at modeling the entertainment factor of games using this approach on our way to a general understanding of human cognition. Note that the aim of this research is not to make a strong shogi program to challenge the top human players. Other approaches are much more likely to be successful here. Also, shogi is just one test environment. We are currently also using chess (joint research) and Go (at our lab) to compare results in similar but different test environments.

In this rest of this section, I will give some more detailed ideas of how to build a *Society of Shogi*, i.e. which types of agents and agencies I think will be needed to result in proper shogi play.

4.1. Shogi Agents

The first thing that needs to be decided is what the primitive agents are in the domain of shogi. As pointed out, the most primitive agents in any domain are the agents concerned with input (perception) and output (action). In the shogi domain, this would be agents concerned with recognizing where each piece is (input) and knowing what each piece can do (output). These agents are initialized in the starting position and updated with each move that is being played.

Starting from this, the most simple K-lines are the K-line that changes the internal representation of the location of a piece and the K-line that updates the squares that pieces can move to based on the changed position. More complicated K-lines could turn on the internal representation of a castle formation or the moves that are needed to get into a desired formation.

Polynemes in shogi could be representations of certain common formations like *yagura* and *bogin attack*. A polyneme for *yagura* would have partial states in multiple agencies. For example, the *Recognize Castle* agency could be in the state 'S7g-G7h-G6g-B8h-K6i' (Fig. 3), the *Build Castle* agency would be in the state 'B7i-B4f-K7i-K8h' (Fig. 4), the moves that are still needed to complete the castle, the *Castle Weakness* agency could be in the state 'strong from the top, weak from the side' and so on.

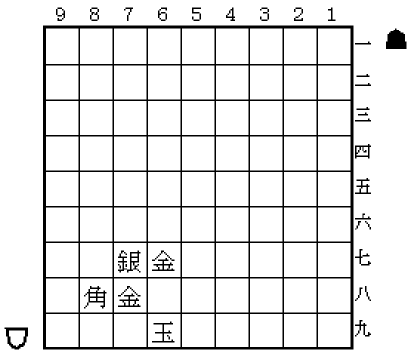

Figure 3: Example state of the *Recognize castle* agency

Build Castle	
1	B7i
2	B4f
3	K7i
4	K8h

Figure 4: Example state of the *Build castle* agency
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4.2. The Recognition Agency

To play a game, three important processes (agencies) are needed: a *recognition agency*, a *look-ahead agency* and a *learning agency*.

The recognition agency has two major sub-agencies: a *context recognition agency* and an *evaluation agency*. The context recognition agency has agents to recognize the following:

- *Strategy*: static rook, ranging rook
- *Castle*: yagura, anaguma, mino, etc.
- *Attack strategy*: bogin, edge attack, etc.

- *Piece attack*: which pieces are in danger of being captured
- *Current plan*: trap piece, attack pinned piece, etc.
- *Mood*: attacking, defending, passive, active, etc.
- *General aim*: go for material or go for mate

The evaluation agency can have agents to evaluate the following:

- Material
- King danger
- Mobility
- King distance
- Forks, pins and ties
- Weak points like the head of the knight

Each of these agencies has to be a hierarchy which is connected through different levels with the primitive agents of piece location and piece movement. An example of a small part of such a hierarchy for defending a piece is given in Fig. 5.

4.3. The Look-ahead Agency

The look-ahead agency also has to have two major sub-agencies: a *move generator agency* and a *search agency*. The move generator agency will be closely linked to the recognition agencies. Examples of move generator agents are:

- Capture piece
- Move attacked piece
- Defend attacked piece
- Attack king
- Play fork
- Attack pinned or tied piece
- Attack weak point
- Move piece closer to king

This is only a small example set. It is expected that strong game players use many different move categories.

The search agency will probably be the most complex one, as this is at the core of problem solving in games and human players do not use a single strategy for problem solving. First, it is important to attach some sort of priority to the moves that are being searched. This should be based on the activity level of the recognition agents that triggered the move generation.

Also, much of human problem solving is based on *satisficing*, i.e. confirming that the intended course of action was correct. Top game players spent a significant amount of their thinking time on checking if there is a problem with what they intend to play. In most cases there is no problem and they will play the move that they initially intended. The

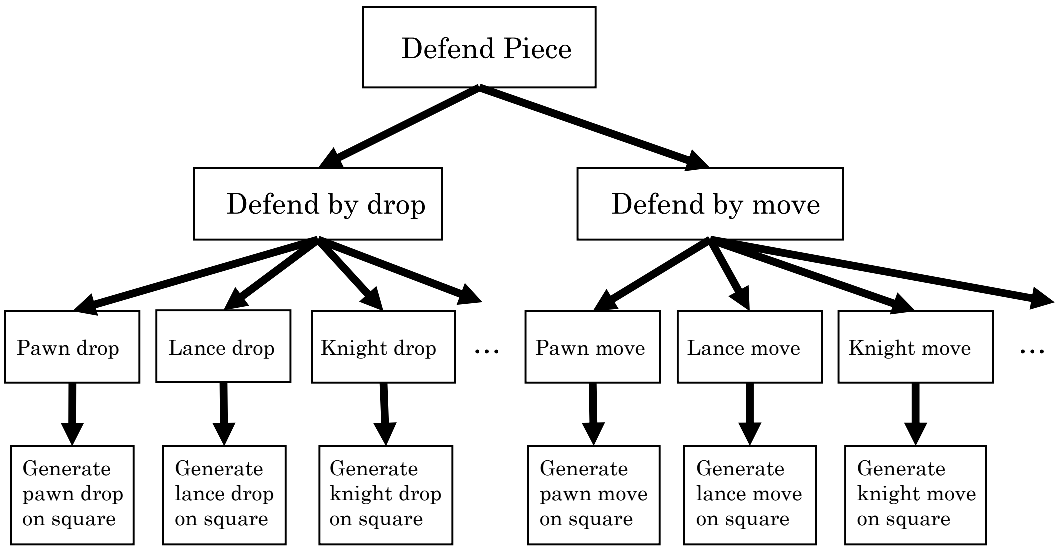

Figure 5: Part of a hierarchy to defend a piece.

interesting and probably most difficult problem solving behavior occurs when a problem is detected. *Feedback* is very important for the problem solving process, but there doesn't seem to be a clear representation of feedback in Minsky's theory, despite the fact that the human brain seems to be wired more backward than forward (Hawkins 2004). Feedback should change the activity levels of the recognizer agents and the move generator agents, giving other moves than the move that was initially intended a higher priority.

4.4. The Learning Agency

Learning is expected to be the most complex activity in the Society of Shogi. The main trigger for learning is overlooking or underestimating a move by a strong player (either the opponent or from game records). Overlooking a move, i.e. not generating the move at all, should trigger a learning process that creates new agents. Agents that create the move are of course necessary, but also recognizer agents need to be created to have the proper context (understanding) of how and when to generate the move.

Underestimating a move can be caused by a problem with the activity level of the agents involved in creating the move. If this activity level is too low, the move will only be considered for a little while or not considered at all. Learning in this case should be to increase the activity level of the agents connected with the move that was underestimated. However, it is possible that the activity level needs to be increased too much, resulting in strange behavior in similar situations. Therefore, it is also possible that new recognizer agents must be created to store the context of a move that was underestimated.

5. Conclusions

It is our belief that understanding what is entertaining and what is not can only come from a general understanding of the workings of the human mind.

In this paper I have given the most important concepts of Marvin Minsky's *Society of Mind* theory about the workings of the human mind and how these concepts can be translated to a game-playing environment.

For general games, the main problem of this approach is the large number of agents and agencies that is needed. Without a learning system, which has not been properly modeled by Minsky, it seems hard to make a system with such a large number of agents.

Therefore, as a first step, we will apply Minsky's theory to classic board games like chess, shogi and Go. In these domains the number of agents and agencies is expected to be small enough to develop the model for learning that is needed in larger domains.

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