Time Perception in the game "The Mind": a Cognitive Model Approach

Bachelor's Project Thesis

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Abstract: The game "The Mind" (Warsch, 2018) is a recent card game that relies on the player's sense of time. The players have to cooperatively play their cards in ascending order without having any form of communication and without knowing which cards are held by the other players. A straightforward strategy of The Mind players is playing their cards based on how much time has elapsed while adapting their time perception to the other players. This research presents a cognitive model in ACT-R capable of playing The Mind that implements this strategy. The model's waiting time increases linearly with the gap between the current card and the card that should be played by the model. The performance of the cognitive model is tested with an experiment. The experiment validates the linear increase in waiting time of the model. Hence, the results suggest that when players play their cards based on elapsed time, their waiting time indeed increases linearly with the gap between the current card and the next card.

1 Introduction

The game "The Mind" (Warsch, 2018) is an exciting new card game that relies on the players' sense of time. The game is like an experiment in which people collaboratively have to come to a similar sense of time.

The Mind is played with a deck of 100 cards, and with 2 to 4 players. The cards all contain one of the numbers between 1 and 100. At the start of each level, all players receive the same number of cards. The players are not allowed to see the cards of the other players. The goal of the players is to play these cards in ascending order without having any form of communication. All players can play their cards at any time, there are no turns.[1]

While the rules of the game are simple, playing the game involves complex cognitive processes. To successfully play the game, players need to agree on what cards to play at what times. The time perception of all players should be tuned during the game to become approximately the same. Studying how this game is played by humans can therefore help understand human time perception better, specifically how humans adjust their time perception to the situation.

To win the game, each player should wait for about the same amount of time with playing their card, given an equal card. The players' sense of time is crucial. Humans usually have a good sense of time in short time intervals. Timing becomes less precise for longer time intervals (Matell and Meck, 2000). Humans are also able to adapt their sense of time, based on experiences. Taatgen and van Rijn (2011) show with their ACT-R model that representations of time intervals in memory are created by a pool of experiences. The recency and match to the current request determine the impact of each experience in the pool on the representation of the requested time interval. During the game-play of The Mind, the players establish a pool of experiences of time that determines their timing. Each time a new card is played by one of the players, a new experience of time is added to the pool. And each time a new card should be played, a time percept is retrieved from the pool of experiences to determine the waiting time.

A straightforward strategy of The Mind players

[1] The game includes some additional features that are beyond the scope of this research.

is playing their cards based on how much time has elapsed. A card close to the current card is played quickly, whereas more time will elapse before a high card will be played. The players wait with playing their cards to ensure that if someone has a lower card, that card will be played first. The question with this strategy is how the waiting time changes with the gap between the current card and the next card that will be played. The current card is defined by the last card played by one of the players or is 0 in case no card has been played yet. One possible strategy may be that players count the time until their count reaches the number they want to play. This would mean that the waiting time increases approximately linearly with the number on the card.

To better understand how humans play The Mind, this paper presents a cognitive model capable of playing The Mind. The cognitive architecture ACT-R (Anderson et al., 2004) is used to create the cognitive model that can play The Mind. This architecture has proven to accurately model many different facets of human cognition. By comparing predictions of the cognitive model to actual human gameplay, we can then determine to what extent the behaviour of humans while playing The Mind is accurately represented by different variations of the cognitive model. This research tests the hypothesis that the waiting time increases linearly with the gap between the current card and the next card played. Optional non-verbal communication that may appear during the game is not incorporated in this research.

A temporal module (Taatgen et al., 2007) is included in ACT-R that models how humans perceive time. The temporal module is based on the model of interval timing proposed by Matell and Meck (2000). This module will be used in this cognitive model and a more elaborate explanation is given in the Method section.

In this paper, the cognitive model capable of playing The Mind will be presented and compared to data of human game play. In the methods section, the cognitive model and the experiment testing the cognitive model will be explained. In the results section, the data of the experiment compared to the performance of the cognitive model will be presented. And lastly, in the conclusion and discussion section, the consequences of the findings and potential future directions are discussed.

2 Methods

2.1 Model

To build a cognitive model capable of playing The Mind, a cognitive architecture is needed. A cognitive architecture implements the theory of cognition at a certain level of abstraction. For this cognitive model, the cognitive architecture ACT-R is used. ACT-R has a high level of abstraction and uses multiple modules coordinated by a central production system. Each module processes a different type of information and communicates through one or multiple buffers. Each buffer can hold one unit of knowledge called a chunk (Anderson et al., 2004). To create a reasonable model of how The Mind is played by humans that can answer the research question: "how does the waiting time change in relation to the gap between the current card and the next card played?", this high level of abstraction is sufficient.

Time perception is a crucial aspect of The Mind. ACT-R has a separate module that processes time: the temporal module (Taatgen et al., 2007). The temporal module can determine time intervals. This module consists of a pacemaker–accumulator internal clock model, as proposed by Matell and Meck (2000). It provides a timer that keeps track of the number of "ticks" that have passed since the timer was started. The timer counts automatically, and the model can access the current tick count via the temporal buffer. The ticks are calculated based on the following equations:

$$t_0 = start + \varepsilon_1 \quad (2.1)$$

$$t_n = a \cdot t_{n-1} + \varepsilon_2 \quad (2.2)$$

In this cognitive model, a is set to the value of 1.0, ε_1 and ε_2 are noise generated according to the default ACT-R settings, and *start* is set to the value of 0.3. The value of 1.0 for a deviates from the default ACT-R value. The default ACT-R value is 1.1 to reflect Weber's law (Taatgen et al., 2007). This law implies that the timing of a time interval becomes more uncertain with the magnitude of the interval (Gibbon, 1977). Therefore, the length of the ticks increases with the interval, resulting in a logarithmic scale. However, the hypothesis tested in this research is that the waiting time increases linearly with the number on the card. Therefore, the timer used by the cognitive model should also be linear and hence the value of 1.0 for a is chosen. The value of $start$ also deviates from the default ACT-R value, this value is chosen to best fit the human data. The values of a and $start$ are presented in Table 2.1 under the parameters time-mult and time-master-increment, respectively.

During the game, the time perceptions of the players adapt to each other to become approximately the same. In the cognitive model, time perception is based on time percept chunks that the model has in its declarative memory. Each time percept consists of a number of ticks that it should wait to play a card with a number that is one higher than the current card. Based on this number, the model can calculate the number of ticks it should wait for any card. At the start, all players have their own sense of time. After each newly played card, a new time percept is perceived and added to declarative memory. This creates a pool of experiences. Each time before a new card should be played, the model retrieves a new time percept that it will use. From the pool of experiences, the current sense of time can be calculated based on all experiences and their recency and frequency (Taatgen and van Rijn, 2011). To incorporate this in the model, an extra ACT-R module is used: the blending module. The blending module is able to retrieve the aggregate result of the whole pool of experiences based on recency and frequency (Lebiere, 1999), instead of retrieving one particular experience. The aggregate result is calculated with the following equation:

$$V = min \sum_i P_i \cdot (1 - Sim(V, V_i))^2 \tag{2.3}$$

where $Sim(V, V_i)$ is the similarity between value V and actual value V_i returned by chunk i, and P_i is the probability of retrieving chunk i as a function of match score M_i and the match scores M_j of all other chunks j calculated with the Boltzmann equation:

$$P_i = \frac{e^{M_i/t}}{\sum_j e^{M_j/t}} \tag{2.4}$$

In this cognitive model, t is set to 0.1. This value deviates from the default ACT-R value and is chosen to best fit the human data. The lower the value of t, the more the system behaves deterministically in retrieving the chunk with the highest match score. The higher this value, the more the system randomly retrieves any chunk that partially matches. The value of t is shown in Table 2.1 under the parameter tmp.

When the game is played in real life, players place their cards on the table when they play a card. The other players are able to see this and react to what they see. In this cognitive model, this process of playing cards does not go via movement and vision but through speaking and hearing. The details of the process of communication between players are beyond the scope of this paper. Therefore, to simplify the model, the communication is done by speaking out the number of the card played instead of doing the actual movement of placing a card on the table. An adjusted version of the "multi-model-talking.lisp" code is used to allow the different models, that represent the different players, to interact with each other. The "multi-model-talking.lisp" code is standard incorporated in the ACT-R software (ACT-R Research Group). The models produce sound through the vocal module and detect sound through the aural module.

Other modules used by the cognitive model are the goal, imaginal, and retrieval modules. The goal module keeps track of the state and remembers which card should be played next. The imaginal module holds information about the current situation that is relevant to the task. And lastly, the retrieval module is able to request information from the declarative memory.

Procedure

The cognitive model consists of two models representing two players. Both models start with the cards they are dealt in their declarative memory. Information about the order of the cards is also already inserted into the model's declarative memory. The process of seeing and processing the cards as well as the ordering process is beyond the scope of this research and therefore omitted.

The models start with retrieving the card they have to play next from their declarative memory. After that, they retrieve a time percept using the blending procedure calculated with Equation 2.3. When all necessary information is retrieved, the models start counting the time. When the counting of one of the models exceeds the waiting time they relate to their card, this model will play its card. A model can play its card by speaking out the number on the card. Both models will then detect this sound and react to the fact that a card is played. When a new card is played, the time perception of the models is updated. The model that did not play its card will create a new time-percept calculated from the card played by the other model and the time it took before this card was played. The model will save this time-percept to adjust its timing to the other player. Besides this, the model that did not play its card also checks whether a mistake is made. When this model detects that the card that is played is higher than its own card, it will report that a mistake is made. A model can report a mistake by speaking out that a mistake is made. Both models will then detect this sound and punish the time percept they used. After the models have updated their sense of time, they check whether they have to retrieve a new card. This is the situation when the model played its own card or when the other model played a card that was higher, and thus a mistake was made. When both models have retrieved the card that they have to play next, they start retrieving a time percept and start counting the time again. When one of the models has played all of its cards, this model will stop. The whole cognitive model ends when both models have played all of their cards.

To let the model play multiple games, the models keep track of the number of cards left in their own hand and the other model's hand. When both models played all their cards, they proceed to the next game. The whole cognitive model will end when the last game is finished.

Parameters

To best fit the human data, and to let the two models run smoothly simultaneously, some parameters of the cognitive model are adjusted. All parameters that are adjusted are presented in the table below, together with their original value:

Table 2.1: Table showing all adjusted parameters.

parameter name	original value	adjusted value
:tmp	nil	0.1
:lf	1.0	0.0
:imaginal-delay	0.2	0.0
:digit-detect-delay	0.3	0.0
:time-master-increment	0.011	0.3
:time-mult	1.1	1.0
:at play-card	0.05	0.00
:at detect-sound	0.05	0.00
:at detect-mistake	0.05	0.00
:at detect-no-mistake	0.05	0.20
:at process-I-played	0.05	0.15
:u detect-sound	0.00	5.00

Besides, to best fit the human data, the models both start with a starting time percept of 2.5 ticks. This corresponds to waiting for 2.5 ticks before playing a card with a number that is one higher than the current card. With *start* in Equation 2.1 set at 0.3 seconds, this corresponds to about 0.75 seconds. The models both start with this starting time percept in their declarative memory.

2.2 Experiment

An experiment is conducted to gather data of actual human gameplay. The waiting times of the participant together with the gap between the previous current card and the card played by the participant were recorded. This data is compared to predictions of the cognitive model to find out to what extent the behaviour of humans while playing The Mind is accurately represented by different variations of the cognitive model.

Participants

Twenty volunteers took part in the experiment. These participants were recruited through the network of the researcher. The age of the participants was between 19 and 55 with a mean of 25. All participants signed the informed consent beforehand. The participants did not receive a reward for participating in the experiment.

Design and procedure

In the experiment, the participant played 5 games of The Mind against a computer. The games were played on a website [2].

[2] The experimental setup can be viewed at the website: https://harmendeweerd.nl/themind/themind.html.

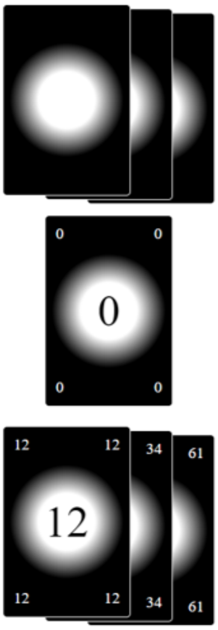

Figure 2.1: Screenshot of the interface showed to the participants at the start of a game.

The figure above shows the interface presented to the participants when the game has started. The participants could play their cards by clicking on it. When a card is played, the card in the middle is replaced by this new card. The website automatically saved the data. The cards given to the participant and the computer in the 5 games were:

(1) Participant's cards: 12, 34, 61
Computer's cards: 40, 70, 83

(2) Participant's cards: 4, 24, 99
Computer's cards: 35, 37, 76

(3) Participant's cards: 30, 45, 90
Computer's cards: 2, 15, 98

(4) Participant's cards: 4, 60, 90
Computer's cards: 10, 95, 99

(5) Participant's cards: 5, 10, 15
Computer's cards: 20, 25, 30

In the first game, the computer did not play its first card before the participant had played its first two cards. After the participant played its second card, the computer played its first card after waiting 7 seconds. Then the computer waited again for the participant to play the last card. In this game, the waiting time of the participants for small gaps was established.

In the second game, the computer again did not play its first card before the participant had played its first two cards. After the participant played its second card, the computer played its three cards after 9, 2, and 18 seconds consecutively. In this game, the waiting time of the participants for small gaps was tested again. Besides this, the participant received data about how long the computer waits with playing its cards.

In the third game, the computer played its first two cards after 1, and 9 seconds consecutively. Then the computer waited for the participant to play its three cards. In this game, the waiting time of the participants for both small gaps and a big gap was tested.

In the fourth game, the computer plays its first card after 6 seconds, even when the participant had not played its first card. Then the computer waited for the participant to play all its cards. In this game, the waiting time of the participants for big gaps was tested.

In the last game, the computer did not play its cards until the participant had played all its cards. This game tested how much the waiting times of the participants vary for a similar gap.

The experiment took place in a quiet room. Before the experiment started, the participant received the instruction of the game. Together with the researcher, one small trial game was done. During the trial game, the participant could get familiar with the workings of the website. After the participant completed the trial game and understood the instructions, the experiment started. After the participant completed the experiment, the researcher and the participant had a small debriefing about the strategy used by the participant.

3 Results

The data of the twenty participants were recorded and processed. The data of three participants were not complete as a consequence of connection issues. Therefore, the data of these participants were excluded from the results. During the small debriefings after the experiment, most participants mentioned that they used a strategy based on waiting for a certain amount of time, related to the number on the card. This is comparable to the strategy implemented in the cognitive model. However, one participant mentioned that he used a strategy of calculating probabilities based on the number of cards left. Since the cognitive model does not use this strategy, the data of this participant is not relevant for testing this model. Therefore, the data of this participant was also excluded from the results.

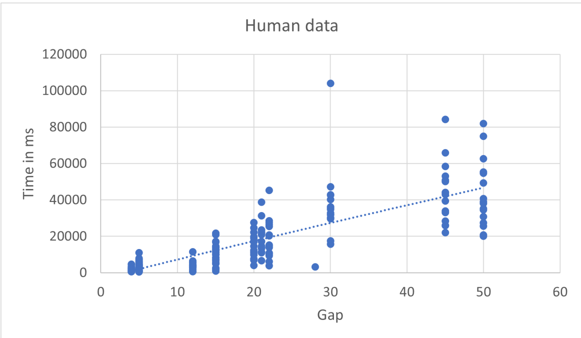

Figure 3.1: Graph of the data of human gameplay.

Figure 3.1 shows the data collected during the experiments. The graph shows the relation between the waiting time in milliseconds and the gap between the current card and the next card in human gameplay. Linear regression is used to test the linearity of this relation. Linear regression shows the relationship between two variables and is, therefore, suitable to test for linearity between the waiting time and the gap. The trendline in the graph is given by the equation $y = -1.0118x^2 + 1047.2x - 3159.8$. Linear regression showed that the x^2 term is not significant (p = 0.7651). The x term is shown to be significant ($p < 0.0001$). Therefore, there is no evidence for a quadratic relation between the waiting and the gap size.

Figure 3.2 shows the data of the cognitive model playing The Mind. The waiting time in milliseconds is plotted against the gap between the current card and the next card.

Figure 3.3 shows the data of humans playing The Mind together with the data of the cognitive model playing The Mind. A significant linear relation between the human data and the model data was found when performing linear regression (F(1,219) = 325.1; $p < 0.001$). The R^2 is 0.5957, meaning that around 60% of the data of the model can be explained by the human data.

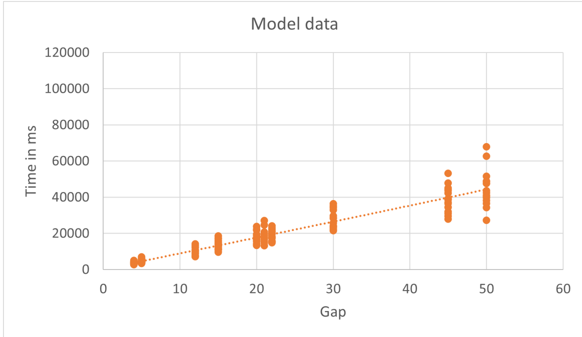

Figure 3.2: Graph of the data produced by the cognitive model.

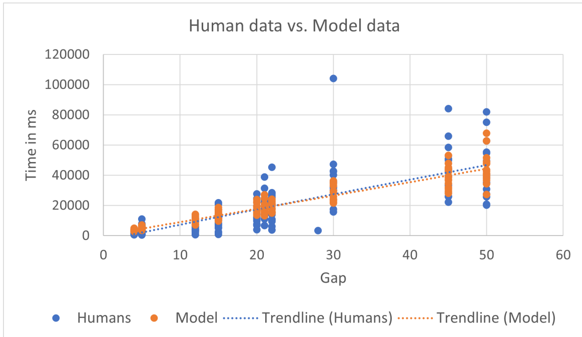

Figure 3.3: Graph of both the human data and model data.

4 Conclusion and Discussion

The data of human gameplay during the experiment suggests that the relation between the waiting time of the players and the gap between the current card and the next card is linear. This answers the research question and supports the hypothesis implemented in the cognitive model. More evidence for the hypothesis is shown when comparing the data produced by the model with the data produced during the experiment. There is a significant linear relation between the model data and the human data, suggesting that the hypothesis implemented in the model is valid as it generates data similar to that of humans.

Besides, the significant linear relation between the data produced by the cognitive model and the data produced during the experiments suggests that the implementation of the model correctly resembles the process of how most humans play The Mind. This supports the theory that human time perception can be represented as a blending of a pool of experiences, instead of a single experience (Taatgen and van Rijn, 2011).

Another interesting finding during this research was that not all participants of the experiments used the same strategy. Most participants based their waiting time on the gap between their card and the current card. This is hence the most common strategy. However, there was one participant that based the waiting time on probabilities calculated with the number of cards left. The cognitive model built for this research only implemented the strategy that bases the waiting time on the gap. However, to get a more exhaustive insight into all the cognitive processes involved while playing The Mind, it would be interesting to also create cognitive models implementing other strategies.

The cognitive model built during this research used a temporal module that deviates from the default temporal module and did not incorporate Weber's law (Taatgen et al., 2007). This was done to be able to test whether the waiting times increased in a linear manner. However, the default settings of the temporal module are tuned to reflect how humans perceive time, which incorporates Weber's law. Therefore, it would be interesting for future research to examine whether humans also expect their waiting time to increase linear, or that their expectation resembles the results of a cognitive model that does not modify the temporal module.

Besides, this research omitted the appearance of non-verbal communication during the game to simplify the cognitive model. However, when humans play the game together in one room, non-verbal communication is unavoidable. When players have a hand with only high cards, they know that they do not have to play a card in the beginning and can relax. The body language can reveal information about the cards of the player. Besides, when a player wants to play a card, it will reach for this card. The other players can detect this and react to it. It would be interesting to investigate in future research whether the addition of this non-verbal communication would affect the results.

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