Cognitive Modelling: Basic Principles and Methods: Final Paper

Rohit Malhotra (r.malhotra.1@student.rug.nl)
Student Number : S3801128
Artificial Intelligence

Abstract

In this paper time interval reproduction will be discussed and modelled. The subjects see an interval of a certain duration and they have to reproduce it. This paper focuses on effect of different memory capacity on the reproduction of the interval. An ACT-R based memory model provided a good description of the interval reproduction and in addition to that it also explained effect of memory on it.

Keywords: Time perception, Interval reproduction, ACT-R, Declarative Memory, Context Effect, Rate of forgetting.

Introduction

Time perception is a very important cognitive ability of human beings. Estimation and reproduction of time interval are most important features to explain many behaviors. The internal timing of human beings is driven by two factors, one the internal clock and other the memory traces of the past experience.

Matell & Meck (2000) improved an existing model on time perception in our brain. In this model, time perception is done by keeping track of pulses. They call this the pacemaker accumulator model. There is a pacemaker that ticks at a certain pace and gradually starts to tick faster as time passes. In this way a certain amount of time corresponds to a certain amount of pulses. According to Taatgen et al. (2004), the temporal module for time estimation acts like a metronome, one that starts ticking slower and slower as the time progresses. Interval is estimated by the number of ticks produced by the metronome. Length of each tick is higher than the previous tick and it includes noise factor, whose distribution is dependent on the previous length of the tick. So amount of pulses are not always the same.

Jazayeri & Shadlen (2010) performed Ready-Set-Go experiment to study reproduction of time interval. In this experiment participants were presented with certain time intervals and asked to reproduce them after hearing it. Their result showed that the reproduced interval had tendency to regress towards the mean i.e participants reproduced shorter interval longer and longer interval shorter. This effect is called context effect and they used Bayesian timing model to explain it. In which the posterior probability of a time interval depends on two probability distribution first the likelihood of the current observation and second the prior distribution of all past duration. But the disadvantage with this model was that it does not take the dynamics of memory into account, i.e., the prior in the model was static and it is not updated when a new temporal context comes in.

Taatgen & Rijn (2011) also proposed a simpler model for reproduction of time interval. Their model is based on declarative memory theory of ACT-R [1] cognitive architecture. They proposed reproduction value is blend of all previous memory traces, and contribution(activation) of each previous encounter decays as time passes. So most recent experience has much stronger weight. They used this model to show context effect.

Memory is an important aspect of the time perception and reproduction. In Maass (2018), they divided participant into three groups based on their scores on MOCA questionnaire: clinically diagnosed with mild cognitive impaired participants (MCI), fail the memory test but NOT clinically diagnosed (healthy fail), healthy participants (healthy-pass). These participants did reproduction task and results are shown in Figure 1. But if context effect depends on the memory, in these results MCI patients showed more context effect than the healthy participants.

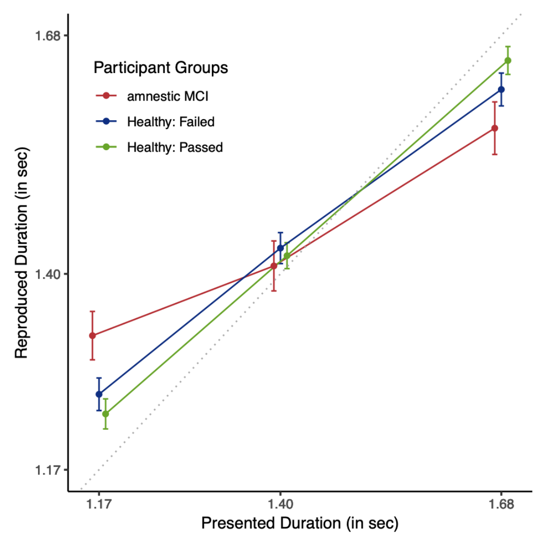

Figure 1: More context effect in MCI patients. Figure taken from Maass (2018)

So we are going to study why people with weaker memory show more context effect than the people with good memory. In order to answer these questions we also examined participants rate of forgetting to see whether we get the same results as in Maass (2018).

Similarly we also studied relation of internal clock precision with the context effect. In a study done by Maa & Rijn (2018), they have shown that clock variability can be assessed

[1] http://act-r.psy.cmu.edu/

as root mean squared error of one-second production task. Based on this we also estimated the variability of participants internal clocks by having them do one-second task and tick-tock task.

Summarizing, we have studied relationship between rate of forgetting and the context effect. Our hypothesis is that people with higher rate of forgetting will have more context effect than with lesser.

Method

Participants were involved in two separate experiments. Experiment 1 was Swahili Vocabulary, this experiment was conducted to determine the rate of forgetting of each participant. Experiment 2 consisted of three separate tasks, **One-Second**, **Tick-Tock** and interval reproduction. Participants performed these experiments individually on their computers and were asked to turn off their phone, and popups, etc, to make sure they were not interrupted during the experiment.

In the following I will describe more details about the above mentioned experiments in terms of participant details, what materials were used and what were the procedures for the experiments.

Participants

Participants were 44 master's students from the University of Groningen, who were enrolled in **"Cognitive Modelling: Basic Principles and Methods"** course at the university. Age group of participants was 21-28 years, of which 29 were male (66%). Mean age of participants was 24.5, mode age was 23 and median age was 24, standard deviation of age was 1.59. 35 participants were right handed (79.5%) and 9 were left handed. All participants gave consent to participate in the experiments.

Experiment1

Materials Participants were asked to learn Swahili-English[2] item-set on slimstampen.nl, which was created by HedderikPI. Swahili-English word pairs are commonly used in vocabulary training for Germanic language speaking participants because two languages use similar letters and phonemes (Sense et al. (2016)). This item-set contained 116 Swahili-English vocabulary pairs. These items were selected from Nelson & Dunlosky (1994). Participants had to respond by typing English word for the presented Swahili word.

Procedure Each person participated for 10 minutes in the experiment. Experiment consisted of two tasks, one was learning a new Swahili-English pair and other was to type in the English word for the presented Swahili word. A new learning task was presented only after strong encoding of all the previously presented words. After presentation of each task participant had to indicate completion of the task by pressing next button, then next task was shown, depending on the situation if all the previously words were strongly encoded then a new word was shown to learn else previous words were shown to type. In typing task if answer was correct then it was indicated as correct and if wrong then it was indicated as incorrect and correct answer was show. Participant also had indication of current time remaining in the experiment, after completion of the participation time no further task was presented or answer to current task was accepted.

Experiment2

Materials Participants performed this experiment on OpenSesame experiment environment (Version: 3.2.5, Kafkaesque Koffka) [3]. Experiment script was provided to the participants, they were asked to run the script (How to run?)[4] and perform the experiment. Experiment script contained procedure for all three tasks, One-Second, Tick-Tock and interval reproduction.

Procedure Participants performed this experiment in one session. At the beginning of the session participant were asked to fill necessary details (participant number and identity distinguishing text) to link data from this experiment to experiment1 and demographic information (age, gender, handedness). This session was divided into total six blocks,one-one each for One-second and Tick-Tock tasks and four blocks for interval reproduction task and they were presented in this same order. A new block was only presented when participants would indicate that they were ready for it, by pressing the space-bar. In the following I will explain each type of block in detail.

One-Second Block In this block participants were asked to estimate a duration of one second. In each trial a tone was produced and their task was to press the spacebar when they thought the tone has played for one second. As soon as keypress was registered tone was stopped and estimate was recorded as difference between onset of sound (+ 70ms to correct for typical soundcard delay) and time of keypress. After start of tone responses were prevented for first 100ms.

In-order to get estimate of their inner sense of time, participants were instructed to not to use any tricks like counting etc. This block had 20 trials and each new trial was presented after random time period, selected from uniform distribution from 2000 to 3000 ms.

Tick-Tock Block In this block participants were again asked to estimate one second duration, but now based on a clock that ticks the seconds away. Before the start of this block five repetitions of "tick/tock" were played to the participant. Then ticks at irregular intervals were played and task of the participants was to press the spacebar one second after the tick and thus play the tock at the right moment. As soon as the keypress was registered trial was ended and difference between onset of sound (+ 70ms to correct for typical soundcard delay) and time of keypress was recorded as estimated one second. This block had 20 trials of one second estima-

[2] https://app.slimstampen.nl//main/all-lessons/lessonPage/77

[3] https://osdoc.cogsci.nl/3.2/download/

[4] https://osdoc.cogsci.nl/3.2/tutorials/beginner/step-13-run-the-experiment

tion and interval between two trials was randomly selected from uniform distribution from 2000 to 3000ms.

Reproduction Block In this block participants were asked to reproduce the duration which they have heard just before. At the start of the trial there were two images one of a dog and other of a frog. Then a trumpet sound was played and dog was animated along with indication to listen. Then as soon as that sound ended, participants were indicated to reproduce the duration of that sound. In order to reproduce they had to press the spacebar for same duration. Keypress started sound, and animation of the frog. Releasing the key ended sound and animation. Then reproduction duration was registered as the difference between keypress and keyrelease. 2 shows one experiment trial of this task.

There were four blocks in this task and each block had 10 trials. Order of blocks was either two blocks of short interval followed by two blocks of long interval, or vice versa, this was determined by participant's number which was asked at the start of the experiment. Only before start of the first block participants were asked to perform three extra trials in which feed-backs on their estimation were also provided. Feed-backs were "too short" if estimation was before the range ($interval \pm 15\%$) and "too long" if it was after the range and "well done" if inside the range. There were two intervals 750ms and 900ms in short block and 900ms, 1080ms in the long block. Delay between two trials was randomly selected from uniform distribution from 2000 to 3000ms.

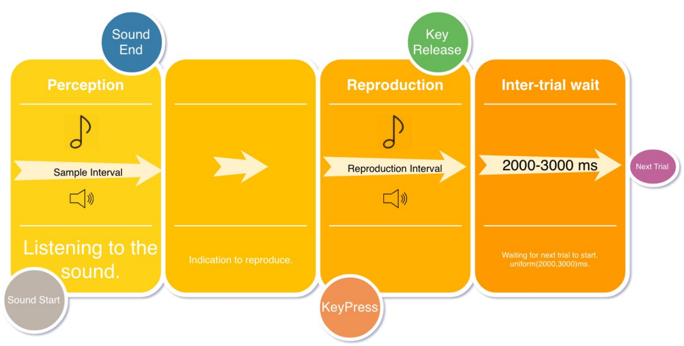

Figure 2: One trial of interval reproduction task.

Results

Figure 3 shows distribution of rate of forgetting of participants. All participants above median are considered as having higher rate of forgetting and similarly below this as lower.

By looking at the Figure 4 we can see that for the long context, short interval (900ms) is estimated higher and the long interval (1080ms) is estimated lesser than the actual. But for short context if we see shorter interval(750ms) it is estimated almost the same but longer interval(900ms) is clearly estimated less. Details of mean and standard deviation of the RT (reproduced time) for participants grouped as higher and lower rate of forgetting are shown in Table1.

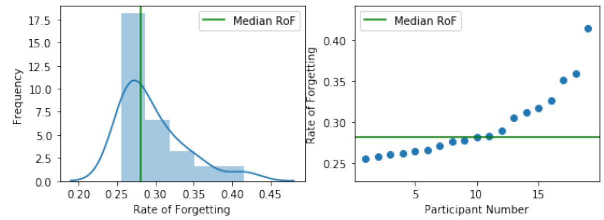

Figure 3: Calculated RoF of participants, from swahili-english experiment.

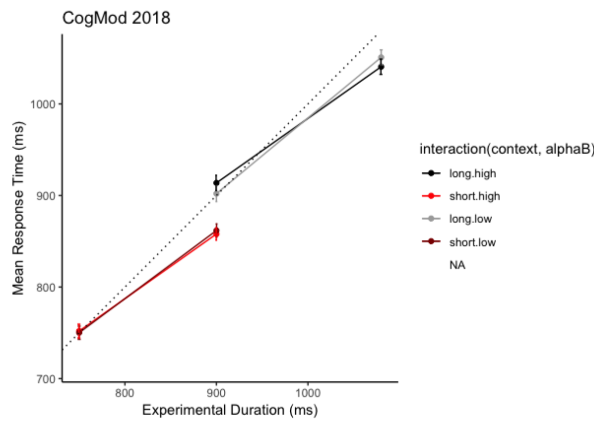

Figure 4: Result of participants with low and high rate of forgetting

We did linear mixed effects analysis of the relationship between reproduced time and other variables. As a pre-processing step in data for better analysis duration and re-produced time were first centered by subtracting 900 and scaled by dividing by 1000,so that the models could converge smoothly. Short Block was coded as as -0.5 and Long Block as 0.5. As a measure of clock variability for both One-Second Task and Tick-Tock Task, root mean squared residuals (pro-dRMSRs) were calculated. In analysis fixed effects were Duration, Context, RoF, and the interaction between Duration and Context, Duration and RoF, Duration and prodRMSRs, Duration, Context and prodRMSRs into the model. As random effects, we had intercepts for subjects. P-values were obtained by likelihood ratio tests of the full model with the

M (SD)	**Short Context**		**Long Context**	
	750ms	**900ms**	**900ms**	**1080ms**
Low RoF	752.68 (103.07)	864.29 (103.11)	904.57 (123.23)	1053.33 (115.80)
High RoF	754.46 (100.93)	860.48 (90.74)	916.25 (111.32)	1043.11 (111.94)

Table 1: Mean and standard deviation of reproduced time

Predictors	Estimate	SE	t-value	p-value
Intercept	-0.170	0.095	-1.790	0.091
Duration	1.068	0.163	6.560	$<$0.001***
Context	0.048	0.007	6.471	$<$0.001***
RoF	0.529	0.318	1.664	0.115
Duration* Context	0.153	0.074	2.064	0.039*
Duration*RoF	-0.894	0.540	-1.656	0.098
Duration* prodRMSRs	-0.255	0.062	-4.131	0.001***
Duration* Context* prodRMSRs	-0.498	0.171	-2.917	0.004***

Table 2: LME analysis of data

effect in question against the model without the effect in question. Results are shown in Table 2.

Model

The goal of the model which we built is to fit the reproduction data of long and short context, of two groups of participants, one with higher rate of forgetting and another with the lower. The model is build in Python.

Model Elements

Pulses When we convert times to pulses in our head, using the pacemaker accumulator model, there is always a certain amount of noise. This noise is one of the the reasons for not having exactly the same interpretations of duration. The noise is always different and therefore the outcomes are, too. Because the clock is ticking slower when the time passes, the length of the pulses is slowly getting bigger. For example: one pulse is 1 second in the beginning and one pulse is 2 seconds after a while. The same amount of pulses corresponds to a longer amount of time when it becomes later. The exact length of the pulses is calculated as follows:

t0 is the length of the starting pulse. The length of every other pulse can be calculated using formula 1.

$$t_{n+1} = a \times t_n + noise(M = 0, SD = b \times a \times t_n) \tag{1}$$

In this equation, n corresponds to the index of the pulse, a and b are parameters that can be set at any value you want. Taatgen et al. (2007) extracted two reliable sets of parameters, in our model are using following:

$$t_0 = 11ms, a = 1.1, b = 0.015 \tag{2}$$

The noise is generated by a default noise function which is implemented in ACT-R. This noise function is described by:

$$s \times \log\left((1 - rand)/rand\right) \tag{3}$$

Using these formulas, we can convert time into pulses and vice versa. You see a certain interval, convert the time into pulses and you store the current time in your declarative memory at the right chunk. The chunk corresponds to the calculated amount of pulses.

Declarative Memory Grote-Garcia & McDowell (2011) give a good definition of declarative memory: ”the conscious recollection of experiences, events, and information used in everyday living. In our experiment you are consciously recollecting information about the interval you stored, so this process takes place in the declarative memory.

The time stamps (pulses) that are stored into declarative memory all get a certain amount of activation. Activation for each chunk **decays** with time. In dm when the information is retrieved the process of blending occurs. In blending information retrieved depends on activation of all chunks related to retrieval query. For each chunk the recall probability is calculated by dividing the activation for that chunk ($e^{A_i/t}$) by the sum of all activation values:

$$P_i = \frac{e^{A_i/t}}{\sum_j e^{A_j/t}} \tag{4}$$

$$A_i = \log \sum_j (t - t_j)^{-d} + \log A + SA_i \tag{5}$$

where A_i is given by equation 5, d = 0.5 and $(t - t_i)$ is the time passed since chunk was last retrieved from dm. In this way, all chunks are used to calculate the activation for the current pulse(chunk). Each of P_i outcomes (for each chunk) is multiplied with the chunk value and all those outcomes are summed to get the blended value.These blended pulses are converted into a time again in order to get the re estimated time interval.

Spreading Activation from goal Eq.5 mentions SA_i, which is spreading activation received from the goal chunk. In declarative memory there is a special chunk which is called goal chunk, it stores value of our current goal. So if our queried chunk matches our goal then it receives extra activation and value of SA_i is proportional to number of chunks that refer to the goal chunk.

Discussion

The goal of this study was to model the effects of different working memory capacity on the context effect. An ACT-R based memory model using blending of memory traces was used to show the context effect. We further used goal module of the ACT-R to show the effect of memory i.e how people with reduced working memory capacity show more context effect.

In our model, effect of memory is modeled using the spreading activation received from goal chunk. People with higher RoF, tend to forget about their goal while they are retrieving chunk. So spreading activation from goal is much lesser in these cases. Which we have modeled using two ga (constant factor in SA_i) values. For participants with higher rate of forgetting it is 0.001 and with lower it is 1.0. Also if they have a weaker memory then maximum spreading will be lesser, this we have modeled using two mas (Maximum Spreading in ACT-R), mas=2 for higher RoF and 0.5 for lower. With these values of constants result of our model is shown in Figure 5.

Due to spreading activation from goal chunk latest interval seen is favoured more compared to previous traces from memory, so participants who have received higher spreading activation(low RoF) will have lesser context effect and vice versa, which was our hypothesis.

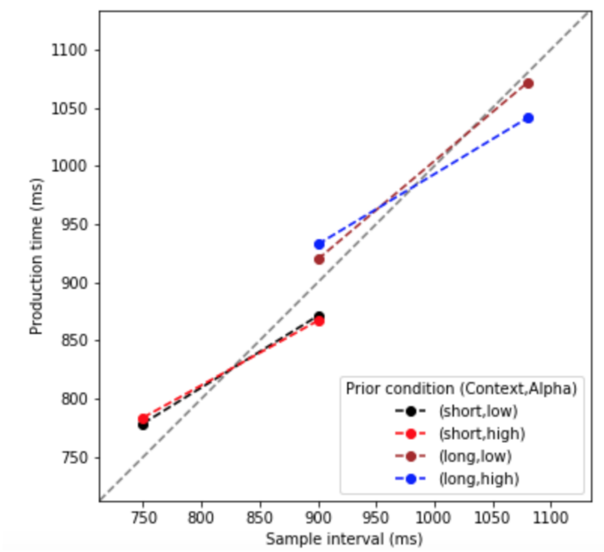

Figure 5: Result from model. Effect of memory is more prominent when the context(length) of the interval is higher

For now we have only considered spreading activation from goal chunk. However, we have not considered other factors like decay factor, mismatch penalty. As a further task we would like to study which of these factors or combination of these factors best describes the relation between rate of forgetting and context effect.

References

Grote-Garcia, S. A., & McDowell, F. D. (2011). Declarative memory. In S. Goldstein & J. A. Naglieri (Eds.), *Encyclopedia of child behavior and development* (pp. 476–476). Boston, MA: Springer US.

Jazayeri, M., & Shadlen, M. N. (2010). Temporal context calibrates interval timing. *Nature Neuroscience*.

Maass, S. C. (2018). Timing deficiencies in amnestic mild cognitive impairment: Disentangling clock and memory processes.

Maa, S. C., & Rijn, H. van.(2018). 1-s productions: A validation of an efficient measure of clock variability. *Frontiers in Human Neuroscience*, *12*.

Matell, M. S., & Meck, W. H. (2000). Neuropsychological mechanisms of interval timing behavior. *BioEssays : news and reviews in molecular, cellular and developmental biology*, *22 1*, 94-103.

Nelson, T. O., & Dunlosky, J. (1994). Norms of paired-associate recall during multitrial learning of swahili-english translation equivalents. *Memory*, *2*(3), 325-335. (PMID: 7584298)

Sense, F., Behrens, F., Meijer, R., & van Rijn, H. (2016, 1). An individual's rate of forgetting is stable over time but differs across materials. *Topics in Cognitive Science*, *8*(1), 305–321.

Taatgen, N., Rijn, H., & Anderson, J. (2007, 08). An integrated theory of prospective time interval estimation: The role of cognition, attention, and learning. *Psychological review*, *114*, 577-98.

Taatgen, N., & Rijn, H. van. (2011, Nov 01). Traces of times past: Representations of temporal intervals in memory. *Memory & Cognition*, *39*(8), 1546–1560.

Taatgen, N., Rijn, H. van, & Anderson, J. R. (2004). Time perception: Beyond simple interval estimation. In *Iccm.*