Retention of Petri Nets: The Performance of Long Term Working Memory on Graphical Material

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Memory Processes

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Petri nets are a family of mathematical modeling languages with a well-established visual representation. They are used both in academia (Desel & Juhás, 2001) and in the private sector (Desrochers & Al-Jaar, 1995) in different variations. The first specification goes back to Petri (1962) who focused on the development of an asynchronous automaton model. Since then the field has largely diverged (Desel & Juhás, 2001).

Since some professionals work with Petri nets on a frequent basis, it can be expected that those develop a different, more advanced perception (in its extended sense) for their domain, meaning that they can remember and recall larger fragments of domain knowledge with a higher accuracy compared to lays of the respective field. Such findings exist for many domains, the most related domains in terms of visual material similarity might be the technical drawings of electrical engineers (Egan & Schwartz, 1979) and mechanical engineers (Moss, Kotovsky & Cagan, 2006). But the findings in the field of expertise research go far beyond that and include domains such as programming (Shneiderman, 1976), music (Sloboda, 1976) and waitressing (Ericsson & Polson, 1988); a more extensive list has been compiled by Oulasvirta and Saariluoma (2006). The reported differences vary between studies: In chess experts simply outperform lays in recalling chess positions (Gobet & Simon, 1996) whereas in domains like map-reading lays recall different aspects of the maps – aspects which are actually missing in the experts' recall (Gilhooly, Wood, Kinnear & Green, 1988). Lays are mostly guided by visual properties of the material (Canham & Hegarty, 2010; Egan & Schwartz, 1979; Moss et al., 2006) – an observation which has been named *perceptual chunking hypothesis* (H. A. Simon & Gilmartin, 1973). However, this hypothesis does not work for experts because experts use their knowledge about the domain to form chunks which are guided by functionality (Egan & Schwartz, 1979; Moss et al., 2006). As an example, Moss et al. (2006) examined for what guided freshmen and seniors in forming their chunks. Freshmen were guided by the principle of proximity: Whichever elements were close to each other were retained as one unit even if those elements did not perform a common task or were not connected. Seniors instead recalled units ordered from input to output and drew each unit together with its functionally related units.

While some of the above-mentioned studies solely measured how lays and experts differ, others also introduced and justified certain theoretical models which account for the performance differences. Performance is used to describe the error rates at the end of the recall and dynamics during the recall, namely the breaks which occur between the recall of the different units. For these units the term *chunk* has been coined by Miller (1956) who differentiates between *bits* and *chunks.* While bits describe each single piece of information, chunks are an agglomeration of bits and according to Miller (1956) only about 7 of them can be kept in short-term memory. While this number is too optimistic for meaningless visual material for which an accurate repetition was only possible for 4 items (Luck & Vogel, 1997), chess masters have greatly outperformed that number by placing up to 178 pieces correctly (Gobet & Simon, 1996). Whatever strategy had been used, it seems rather naïve to believe that this was possible by having only 7 Miller chunks available, at some point they assume that one participant formed up to 15 chunks. Gobet and Simon (1996) differentiate in their model between clusters which are derived from the chunks of Chase and Simon (1973b) and describe familiar patterns within the material and templates which have some slots in which chunks can be filled in. By nesting clusters in templates, the chunking (from now on both clusters and templates are referred to as chunks) turns hierarchical. Empiric evidence further comes from Moss et al. (2006). But chunks do not only nest, they also overlap (Reitman, 1976): Some chunks on a low hierarchical level are part of several higher-level chunks. Methodologically chunks have been identified by performance measures. Quite often Inter-Response-Time (IRT) analyses have been performed (e.g., Egan & Schwartz, 1979; Reitman, 1976) which was initially proposed by Chase and Simon (1973a). Another source of information has been the switch of looking at the source and the target during a copying process (Reitman, 1976) and comparing the chance of making errors at certain elements during the recall phase (Moss et al., 2006).

The most common approach in expertise literature is the immediate recall of the material after a short presentation time. The recall condition is especially interesting because of its dynamics and the richness of errors which happen during the process and which can give many hints about the underlying processes. Well-known effects like the primacy and recency effect have been found (Gobet & Simon, 1996) and a classification of errors into error of omission and error of commission (Chase & Simon, 1973b) helped to understand the differences between lays and experts better. The short presentation time prevents the participants to learn the material. Empiric findings of verbal learning tasks show that it takes approximately 10 seconds to transfer one chunk from the working memory to long term memory (Newell & Simon, 1972). While the exact number of seconds might vary (cf. e.g., Egan & Schwartz, 1979), longer time spans like e.g. 40 seconds make error score differences between lays and experts disappear (Moss et al., 2006). The experts' advantage is grounded in that once a chunk is stored in the long term memory, it can be recognized and utilized within much shorter time spans (e.g., Gobet & Simon, 1996). This altogether is the framework in which expertise has been mostly dealt with. Long term memory is mainly regarded as the expertise database for recognizing chunks. The theory of long-term working memory elaborates on the contribution and nature of the long term memory to the processes which are traditionally attributed to working memory (Ericsson & Delaney, 1999; Ericsson & Lehmann, 1996). Once chunks are transferred to long-term working memory, which can take as little as 200ms (Ericsson & Delaney, 1999) but can go up to 2s (Ericsson & Polson, 1988) for more complex chunks, they are virtually safe-guarded (Gobet & Simon, 1996; Oulasvirta & Saariluoma, 2006). This nature of long-term working memory allows experts to continue their work after interruption without any information loss under most conditions (Oulasvirta & Saariluoma, 2006). Lays by contrast suffer much from such an interruption because they lack of appropriate chunks in long-term memory. Hence most task-related memories are irrecoverably lost after task interruption (Oulasvirta & Saariluoma, 2006).

Petri Nets as a Visual Modeling Language

Petri nets are used to model systems by means of a graphical language(cf. Reisig, 2013). Goodman (1968) proposes a framework with rich vocabulary for how to communicate about symbols and their representations; an application of that vocabulary to informal diagram-style drawings was conducted (Kosslyn, 1987) as well as to more formal systems, such as UML (D. Moody & van Hillegersberg, 2009) and $i*$ (D. L. Moody, Heymans & Matulevičius, 2010). The proposed vocabulary is applied hereafter.

The Petri net type this study deals with is the elementary system net (cf. Reisig, 2013). It is one of the most basic Petri nets which can be understood by professionals as it is one of the first Petri net types which are taught at university. It only consists of places, transitions and directed arcs; the visual vocabulary is depicted in figure 1 (see appendix A). Even if professionals have not worked with elementary system nets for a while, the visual vocabulary of their domain is larger, never smaller. The visual language of the Petri nets has a comparably short history. Petri and Reisig is said to have invented the visual notation as early as 1939 (Petri & Reisig, 2008). However, the first scientific publication about Petri nets did not include any visual syntax (cf. Petri, 1962) which then appeared shortly after (e.g., Peterson, 1977; Petri, 1977, 1980; Reisig, 1979).

A Petri net can be understood and examined as a mathematical, directed graph: The places and transitions are the vertices and the arrows are the connecting edges. This relationship both in mathematical and visual terms allows to transfer findings from the research of graph aesthetics which is especially interested in layouts. Performance-based measures such as time and error have given insight into the consequences of layout decisions (Ware, Purchase, Colpoys & McGill, 2002). Measurements such as eye-tracking and questionnaires give insight into how and why certain layout decisions are difficult (Huang, Eades & Hong, 2008). It is argued that time and error can not give full insight into graph comprehension: Some visual search problems can be solved in the same amount of time but with a different subjectively experienced difficulty (Huang et al., 2008, 2009). This study can not fully cover possible influences of the layout aspect. As a Petri net is a mathematical graph, the same Petri net can be depicted using several layout algorithms resulting in different graphical representations of the same system. Hence in this study it is attempted to use a layout system which is consistent with the current Petri net literature. In specific, in this study the Petri nets are aimed to be lay-outed similar to *Understanding Petri Nets* (Reisig, 2013).

Study 1

This study is designed as a pilot study and serves to identify the appropriate difficulty for the Petri net material. The amount of places and transitions and their interconnection should make the task feasible, meaning the recall rate should be far above a randomly drawn new Petri net, but still each recalled drawing should contain some error. Successful analyses have been conducted with accuracy measure from 58% correct recall (Egan & Schwartz, 1979) up to 95% (Moss et al., 2006) which is hence taken as the desired lower and upper boundary respectively.

Method

Participants. Three first-year students, three third-year students who have taken at least one Petri net class and three scientific employees who work with Petri net related material on a daily basis shall participate in this study. The students' participation in experiments is mandatory and part of their curriculum, the scientific assistants get cookies as a reward.

Materials. Petri nets are randomly generated (cf. Appendix B) and visually formatted (cf. Appendix C). A range of 5 and 30 graph elements (n) is used with a number of interconnections (f) between $f = n - 1$ and $f = round(3/2 * n)$. Grid lines are drawn onto the background so that each place or transition is on an intersection of one of the vertical and horizontal lines.

Procedure. In the beginning the participant is introduced in using 'The Reference Net Workshop' (Theoretical Foundations Group of the Department for

Informatics of the University of Hamburg, 2015) as a tool for drawing Petri nets. Further participant is informed that any element which is not on one of the intersections between the vertical and horizontal lines is removed during the scoring process. Each participant does 13 runs from which the first run is discarded as a demo run. In that way each participant sees 13 different Petri nets. The participant sits in front of the screen and is presented one of the generated Petri nets for 5 seconds. After that immediately the recall phase starts. Using 'The Reference Net Workshop' the participant is asked to reconstruct the previously seen net. On the background the same grid lines are presented and the participant is asked to position the places and transitions on the grid lines as the participant has seen it before. After the participant believes that everything which could be remembered has been drawn, the file is saved, printed and closed. The participant is then asked to indicate the used strategy on the print-out and circle which symbols were grouped together.

Scoring

The scoring is inspired on a previous study on mechanical engineers (Moss et al., 2006) which used an extended scoring system of Chase and Simon (1973b). The scoring of each recall is done in the following manner:

1. Each place and transition which is not drawn on the grid intersections is deleted (including the arcs which connected the deleted element with other elements).

2. Each place and transition which has been omitted on the grid is added to the element omission score.

3. Each place and transition which appears on a wrong position on the grid is added to the element insertion error score.

4. Each arc which connects two previously unconnected elements is added to the arc wrong connection score.

5. Each arc which is omitted is added to the arc omission score.

6. Each arc which points into the wrong direction is added to the arc wrong direction score.

The total weighted error score for a drawing is the weighted sum of all the errors mentioned above. Each error score is weighted with 1 except the arc wrong direction score which is weighted with 0.5.

Data Analysis

For each participant and each Petri net first the error score is calculated. Then correct recall score is calculated as a sum of all correctly positioned elements. Then the ratio of the correct recall score to the sum of both the total weighted error score and the correct recall score is calculated. If this ratio is in the range of 58 to 95%, it is selected as appropriate material. Otherwise the Petri net is discarded. Further the Petri nets are ranked according to their ratio and the rank list is partitioned into three proportions of similar sizes. The partitions are labeled with their respective difficulty level, viz. easy, medium and difficult.

Study 2

In this study the prepared material of the last study is used in a similar setup. As a new component a distractor task is added to deteriorate the visual-spatial sketchpad (cf. Baddeley, 1986). Further a second measure, the inter-response time analysis, is taken, to gain more insight into the nature of chunks.

Method

Participants. 10 first-year students, 10 third-year students who have taken at least one Petri net class and 10 scientific employees who work with Petri net related material on a daily basis shall participate in this study. As number of professors and teaching assistants of the University of Hamburg might not be sufficient, assistance from other universities which are also involved in Petri net research might be asked to help. The students' participation in experiments is mandatory and part of their curriculum, the professionals get some cookies as a reward. Having participated in study 1 excludes the participants from study 2.

Materials.

Petri nets. The Petri nets which have been approved in study 1.

Distractor task. An unsolvable 15-puzzle (cf. Ratner & Warmuth, 1986) which runs as a program on the same computer

Procedure. In the beginning the participant is introduced in using 'The Reference Net Workshop' (Theoretical Foundations Group of the Department for Informatics of the University of Hamburg, 2015) as a tool for drawing Petri nets. Further the participant is informed that any element which is not on one of the intersections between the vertical and horizontal lines is removed during the scoring process. Each participant does 13 runs from which the first run is discarded as a demo run. The pool of Petri nets for one participant contains 6 drawings connected with the distractor – no distractor condition. In the no-distractor condition the net will be shown immediately whereas in the distractor condition between the presentation and the recall a 30s delay happens. The six drawings shown in both conditions equal 12 runs.

For each run the Petri net and its connected condition is drawn randomly from the pool. The participant sits in front of the screen and is presented the drawn Petri net for 5 seconds. Depending on the drawn condition either the distractor task is shown or the recall starts immediately. Using 'The Reference Net Workshop' the participant is asked to reconstruct the previously seen net. Mouse clicks and the screen are recorded throughout the process. On the background the same grid lines are presented and the participant is asked to position the places and transitions on the grid lines as the participant has seen it before. After the participant believes that everything which could be remembered has been drawn, the file is saved, printed and closed. The participant is then asked to indicate the used strategy on the print-out and circle which symbols were grouped together.

Data Analysis

Performance Analysis. First the error scores are calculated as described in *scoring* of study 1. A mixed-design analysis of variance (ANOVA) with the Petri net difficulty level (simple, medium, difficult), the distractor task and the total weighted error score as a within-subjects factor and expertise level as the between-subjects factor is conducted. As a post-hoc test Tukey's HSD is chosen. Significant differences are expected between the three groups and between the three Petri net difficulty levels. First-year students are expected to show significant differences between the distractor task and the no distractor task condition while scientific employees are expected not to have a significant difference.

Inter-Response Time Analysis. The mouse clicks and screen recordings are analyzed using a single-linkage hierarchical clustering algorithm (cf. Moss et al., 2006). The found chunks are supposed to correspond to the units indicated by the respective participant. Since each drawing was both presented in the distractor and no distractor condition, for the same drawing for each participant two hierarchical clusters exist. They are compared using the correlation between the cophenetics of each hierarchical cluster (cf. Fowlkes & Mallows, 1983). The two cophenetics are expected to strongly correlate for scientific employees since their are expected to be unaffected by the distractor condition whereas a rather low correlation between the two cophenetics is expected for first-year students. In the no distractor condition first-year students are expected to have rather complex (probably both nested and overlapping) chunks in working memory which help to recall the drawing with comparably little error. In the distractor condition first-year students need to rely on incidental encoding to their long-term working memory. Maybe the presented drawing can utilize existing knowledge about superficially similar visual languages like flow chart diagrams or other, probably highly personal, mnemonic strategies. Without making elaborated assumptions about the used strategies, they are supposed to result in a different cluster than in the immediate recall condition.

Implementation of this Project

The experiment tried to target at many yet not well understood spots and it is novel in several aspects. First, the expertise studies mostly focused on professions for which memorizing material added significant value for the professionals' daily life(cf.

Oulasvirta & Saariluoma, 2006). Whether this is the case for Petri nets has yet been unexplored. This study helps to identify for which kinds of tasks long-term working memory can be helpful. The special nature of Petri nets is that their concept is quite abstract since they only describe how different states are interrelated, which is far from the previous studies which mostly focused on work in which the configuration resembled a specific meaning, e.g. winning or loosing a game or delivering the right dish to the right table. Second, this study looks not only at whether the chunks of lays show a different quality but it also examines in how chunks are deteriorated. This gives some valuable insight in how information declines – whether mainly the interrelations between the low-level chunks suffer (cf. Moss et al., 2006) or whether more, new patterns of recall errors can be observed.

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Appendix A

Visual vocabulary of an Elementary System Net

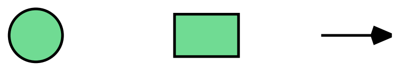

Figure A1. A circle depicts a place, a rectangle depicts a transition and an arrow depicts and arc. The arrow connects places with transitions and can be bent for that purpose. The green color is the standard color of the

Appendix B

Random Petri Net Generation Algorithm

```
Input
  n: number of graph elements
  f: number of interconnections
Output
  P: set of places
  T: set of transitions
  F: set of f el P x T U T x P


Algorithm
  tmp := gaussian(location=n)
  while tmp < 0:
    tmp := gaussian(location=n)
  sizeP := n - tmp
  sizeT := n - sizeP
  P := {p_1, p_2,..., p_sizeP}
  T := {t_1, t_2,..., t_sizeT}

  P_2 = {}
  T_2 = {}
  p_last := random element from P
  t_last := random element from T
  while f > 0:
    p_Pool := P \ P_2 if (P \ P_2) != {} else P
    t_Pool := T \ T_2 if (T \ T_2) != {} else T
    p := random(p_alt, random element from p_Pool)
    t := random(t_alt, random element from t_Pool)
    P_2 := P_2 U p
```

```
T_2 := T_2 U t
if random(TRUE, FALSE):
  F := F U (p, t)
  p_last := random element from P_2
  t_last := t
else:
  F := F U (t, p)
  p_last := p
  t_last := random element from T_2
f--
if places or transitions are not yet connected:
  discard Petri net
```

Appendix C

Layout Algorithm

```
Input
  P: set of places
  T: set of transitions
  F: set of f el P x T U T x P
Output
  Layout


Algorithm
  Draw grid
  Search for whether there is p el P with no incoming arc
  If yes: P_2 := all p el P with no incoming arc
  Else: P_2 := {random p el P}
  i := 0
  while F_2 != F:
    draw all p el P_2 on the ith grid line vertically arranged if not yet present
    draw all t for which (p, t) el F on the (i+1)th grid line if not yet present
    draw the arcs between p and t for all drawn t if not yet present
    P_2 := {p | (t, p) el F for all drawn t}
    F_2 := F_2 U (t, p) U (t, p) for t, p part of the drawing
    i++
```