The Impact of Vertical Hierarchization Representations on Diagram Understandability

(Master Thesis Proposal)

1 Introduction and Motivation

In the field of software and systems engineering, models play a vital role. They are generally used for planning, implementation and maintenance of software systems and are intended to reduce development time and costs while improving sustainability [1].
In addition, models are indispensable when it comes to developing an understanding of software systems. By abstracting system properties, they reduce system complexity to such an extent that the reader is able to solve intricate system problems and form corresponding decisions.

An important model type in system design are statecharts. In the Unified Modeling Language (UML), statecharts are the primary means of visualizing and communicating system behaviour between different parties. They allow the mapping of system states and their transitions to model dynamic behaviour and event-driven changes. Furthermore, they provide an option to simulate modelled system behaviour.

However, due to the rapid growth of structural and behavioural aspects of software systems in practice, corresponding statecharts quickly become more complex. The underlying software domain gets more comprehensive and the size of diagram elements and their interrelationships increase. It is well known that these factors significantly affect the understanding of a model [2]. Therefore, different approaches exist to compensate for model complexity at the design stage. One common approach is vertical hierarchization [3]. Thereby hierarchy is created by abstracting sub-states from an existing statechart model. This reduces the size and complexity of the higher-level model, since further details remain hidden behind the introduced sub-state.

Vertical hierarchization is expected to reduce the mental effort required to understand a model. Yet, the introduction of sub-models leads to a spatial distribution of information sources that must be considered by a reader in order to capture the overall picture of the model. The resulting split-attention effect can in turn lead to an increase in mental effort, which may counteract the positive effects of sub-state abstraction [4].

[4] proposes a theory according to which there is an association between model hierarchization, split-attention effect and the question used to assess model understanding. Especially in the context of UML state diagrams, however, this has not yet been thoroughly investigated.

Therefore, the following work aims at helping to close this research gap. The influence of different representation formats (i.e. varying degrees of the split-attention effect) on the understandability of a vertically hierarchized UML statechart is investigated in an empirical study. A model is used, which has been created for a system in practice.

2 Related work and Problem Statement

In order to effectively benefit from the use of models, it is important to ensure that the readers addressed can actually understand the model. A lack of model comprehension can lead to critical defects and miscommunications during the various phases of system development and maintenance. Therefore, the question of how model understanding can be promoted and facilitated is crucial for the application of models in practice.

Variables affecting model understanding have already been intensively studied in scientific literature [5] [6] [7]. Among the main factors identified were size and diagram complexity in terms of element interrelations. Even though both factors are closely intertwined with the inherent size and comprehensiveness of the underlying software system, vertical hierarchization provides a prominent means to reduce model complexity [8][3]. Individual parts of the model are combined and abstracted, whereby the corresponding model part is divided into several hierarchy levels. The combined abstracted state in the top-level model is therefore referred to as a sub-state or compound state indicating that further details are mapped to it. To the point of writing, the effects of vertical hierarchization on model understanding are still not conclusive in scientific literature.

In the context of statecharts, [9][10] were some of the first to investigate the effects of vertical hierarchization on model understanding. In the years 2005 to 2009 they conducted a series of empirical studies. However, their results were by no means consistent. While some experiments reported positive effects [9], others reported no significant effect at all and other experiments even showed a negative impact of hierarchization on model understanding [10]. In 2009, they conducted a meta-analysis of their previous work to gain a better understanding of the potential reasons leading to such discrepancies in their findings. They finally conclude that their results may be affected by the previous modelling experience of the participants.

Approximately two years later, [4] take up the work of [10] and introduce the split attention effect within the framework of the vertical hierarchization of software models. Thus, they offer a possible determining factor for model understanding that goes beyond the explanatory approach of varying subject expertise. Based on insights from cognitive psychology, [4] identify two opposing effects: abstraction and split attention.

Abstraction describes the positive effect of vertical hierarchization by combining areas of the model into sub-states. Such a sub-model encapsulates information and thus makes it possible to hide it, thereby reducing the complexity of the top-level model. This decreases the number of model elements to be considered by the reader and consequently the mental effort required to understand the model.

On the other hand, the use of sub-states implies that the reader must divide his attention between sub- and top-level model. In order to gain an understanding of the entire model the reader has to mentally integrate the information from both models and sometimes even across several pages. This counteracts the benefits gained from abstraction and increases the mental effort required to understand the diagram.

The theory of [4] is closely related to the cognitive load theory (CLT). One of the underlying assumptions of the CLT is that human working memory is limited in both, capacity and time when processing and holding information. Another assumption is the construction of schemata in long-term memory to organize and maintain knowledge. The objective of CLT is to guide instructional design in such a way that it overcomes working memory limitations and enables a successful comprehension and problem solving process. CLT distinguishes three different sources of memory load: intrinsic cognitive load (ICL), extraneous cognitive load (ECL) and germane cognitive load (GCL) [11]. The assumptions of the CLT also apply to the understanding of a complex model. In this context, the three load types can be defined as follows:

- ICL is linked to the number of diagram elements, their relations and the domain complexity.
- ECL results from the mental effort and the requirements that arise from a sub optimal model representation. A model visualization that favors a split-attention effect is therefore directly associated with an increase in ECL.
- GCL represents the amount of mental resources and effort a reader has available to exclusively invest in model understanding [11].

In 2013 [12] examine their theoretical findings in an empirical study in the context of business process models. They compare two conditions: flat non hierarchized models versus vertically hierarchized models. In the latter, each sub-state is presented on its own page. They argue that both the split-attention and the abstraction effect are maximal in the hierarchized model representation in contrast to the flat representation format.

Their results then actually support their proposed theory on the interplay of abstraction and split-attention effect in vertically hierarchized models. They confirm the abstraction and split attention effect as opposing forces which can predict the impact of hierarchization on model understanding. In addition, they find evidence for the moderating effects of the question intent on the impact of both effects on comprehension performance. Hence, a question posed may benefit or suffer from hierarchization.

Following on the work of [4], [13] investigated the impact of vertical hierarchization on the understandability of large size architectural component models. They stated that, in the context of component models, the abstraction effect resulting from hierarchization has a significant positive influence on model understanding, whereas the split-attention effect does not seem to have any influence.

[13] explain their results with the static character of component models. This makes them less susceptible to the effects of divided attention. If associations between components are distributed across different model areas or pages, then this purely structural information is easier to integrate than in the case of dynamic behaviour information as for example given in statecharts. Here, the connections between sub-states consist of event-based transitions, which may be linked to certain logical conditions. All this information is relevant for the correlation of states and must thus be integrated in a successful model comprehension process.

Only recently, [2] conducted an empirical study, in which they applied the theory of [4] in the context of more complex business process models. In contrast to the work of [12], they examined models used in practice and compared three representation formats: without hierarchization, vertical hierarchized and clustered, whereby sub-processes are nested in their respective top-level processes and thus form coherent blocks or clusters on the same hierarchy level and vertically hierarchized with each sub-process presented on a separate page.

[2] found support for the hampering effects of the split-attention effect on model understandability. This was evident in the finding that in tasks concerning the collection and understanding of information in sub-processes, the effectiveness score (number of correctly answered comprehension questions) was lower in the vertically hierarchized representation group, in which sub-states were presented on separate pages, as in the two other groups. In addition, they found that the two flat representation formats displaying the model on one page are perceived as easier to understand. Interestingly, no differences in model understandability were found with regard to the task efficiency, measured by the time used to answer the comprehension questions.

On the basis of the presented previous research on model understanding, two things have become apparent. On the one hand, the work of [4] has had a strong influence on further research. On the other hand, the empirical studies carried out so far have some notable limitations.

All studies presented, with exception of the work by [2], examined models that were developed specifically for research purposes and are not used in practice. Consequently, the complexity of the models considered was comparatively low. The models of [10] contained only about 25 states. In the empirical investigation of [4] only a hierarchy depth of one was achieved by vertical hierarchization. In order to rule out insufficient complexity as a reason for the previous results, it is necessary to re-examine the theories and findings in the context of more complex models.

Most of the studies carried out dealt with business process models. Therefore, it should be investigated whether similar results can be achieved in other areas, such as statecharts, in order to generalize and further support previous findings.

The studies that followed the work of [4] mostly examined two forms of representation. Flat and non-hierarchized models compared to vertically hierarchized models with subcomponents presented on separate pages. As already argued by [4], the latter condition should maximize both the abstraction and the split-attention effect, while the first condition neither benefits from abstraction nor is affected by divided attention. Only [2] examined a third condition, the clustered representation, in which they attempted to maximize the abstraction effect while at the same time minimizing the influence of split-attention.

To the author's knowledge, none of the previous studies have attempted to gain insights into how people actually proceed during the comprehension process. The theory of [4] and the investigations of other studies focus mainly on cognitive and reader-specific aspects, such as modelling competence, to explain the effects of different representation variants on model understandability. Thereby they neglect, for example, the option that the different representation variants themselves may promote specific interaction patterns during reading, which in turn effect model comprehension.

Hence, the influence of different representation variants of vertically hierarchized models has not yet been sufficiently investigated. It should therefore be examined whether, in addition to the clustered representation, further representation formats can be established, which reduce the negative effects of split-attention and at the same time benefit from abstraction both in terms of the effectiveness and efficiency of understanding. In this context, it should also be further investigated how people proceed in the understanding process and whether this results in patterns for the different representation formats that can be exploited towards a better model understandability. This would not only complement the results of [2], but would also foster and develop existing research and practice.

3 Purpose of the Study

With regard to the preceding two chapters, this work has the following objectives:

- Extending previous research on model understanding in the context of a complex statechart model developed and successfully used as a prototype in the practice of autonomous railroad vehicles.
- Complementation of the findings by [2]. Three representation variants are compared in regard of their impact on model understandability:
  - a cluster representation as proposed in [2]
  - a vertically hierarchized representation in which each sub-state is presented on a separate page, as in the case of [12] and [2].
  - a vertically hierarchized representation variant that attempts to reduce the degree of split-attention effect compared to the above variant.
- Gathering data to extend research on eye tracking and model understanding.

The research is conducted in the form of an empirical study.

4 Supplementary Literature

Literature on Eye Tracking and UML Diagrams
Since eye tracking will be used in the proposed study, this section presents research that applied eye tracking techniques in the context of UML model investigation.

Eye tracking is a commonly used method for examining different diagrams. However, the studies found examine aspects other than vertical hierarchization.
For example, [14] use eye tracking to identify specific characteristics such as layout and color that are most effective to assist the reader in a particular task.
The works of [15], [16] and [17] investigate the influence of different design patterns on the reader's understanding.
Other papers, such as [18] concentrate on the layout of diagrams, how respondents read a diagram, and the influence of the layout on the respondent's cognitive load while solving problems.

In general it can be said that none of the studies that used eye tracking where directly concerned with the hierarchization of a diagram, the different representations and the influence on the reader's understanding. Furthermore, in order to simplify eye-tracking, the investigated material is usually chosen in a way that it fits on one page or screen and the reader often cannot freely interact with the investigated diagrams. This influences the natural behavior of the respondent when dealing with the models. Due to this limitations, the diagrams examined are often less complex and smaller.

In conclusion, the literature found provides an incentive for further investigations using eye-tracking, especially for more complex models presented on separate pages. However, it is also used as an introduction in the context of this study to gain an impression of how eye tracking has been used as a methodology so far and which variables were considered and analysed.

Literature from Psychology
The implications of the theory of [4] are closely related to the CLT. However, CLT has its roots in

learning psychology and is focused on instructional design. For example, the split-attention effect has already been intensively investigated in the field of learning. These findings should be examined and, if applicable, transferred and applied in the context of this work.

Basics of Statecharts, Tools and Guidelines for the Creation of Diagrams
Given that this work focuses on UML statecharts a solid knowledge of the basics of such models is indispensable. Not least because, an own representation variant of a vertically hierarchized model has to be developed. Thus, the following literature deals with the foundations of statecharts and design guidelines for their creation.

Object Management Group. Unified Modeling Language-UML Resource Page [19]
The Object Management Group has included statecharts in the UML specification. Therefore, it represents an important basis for deepening the knowledge on statecharts.

The "Physics of Diagrams": Revealing the Scientific Basis of Graphical Representation Design [3]
The objective of this work was to collect and structure the various differing and contradictory guidelines from literature. It presents 81 guidelines and seven fundamental principles that deal, among other things, with the understandability of diagrams and vertical hierarchization.

In addition to the basics and guidelines for creating statecharts, the author must familiarize himself with the Stateflow tool to be used for the empirical study of this work. For this purpose, the official documentation of MathWorks is consulted [20].

5 Research questions and/or Hypotheses

Based on the problem statement and the purpose of the study, the following hypotheses will be tested in the course of this thesis:

HP1: The self developed representation variant of the vertically hierarchized statechart model will result in a significantly higher model comprehension.

The first hypothesis is based on the assumption, that the self developed representation should provide the advantages of abstraction while keeping the split-attention effect at a minimum.

HP2: The rating of the ICL of all three representation variants of the vertically hierarchized statechart model will show no significant differences.

This hypothesis follows from the fact that the model itself and the vertical hierarchization remain the same across the investigated groups. Only the representation format differs.

HP3: The rating of the ECL of the representation variant that displays each sub-state on a separate page will be significantly higher compared to the other groups.

The third hypothesis follows from the assumption that the split-attention effect can increase with the number of separate pages to be considered and from the fact that an increased ECL is associated, among other things, with an increased level of divided attention [11].

HP4: The rating of the GCL of the self developed representation variant will be sig-

nificantly higher compared to the other groups.

This last hypothesis is a consequence of the two above. Supposing the self-developed representation format reduces the ECL, then it can be assumed that these mental resources are freed up to invest in the process of model understanding.

6 The Design - Methods and Procedures

In order to test the hypotheses presented in section 5, an empirical study will be conducted. The design and execution of the study is oriented towards the guidelines provided by [21]. Thus, the experimental process is divided into the four steps depicted in Fig. 1.

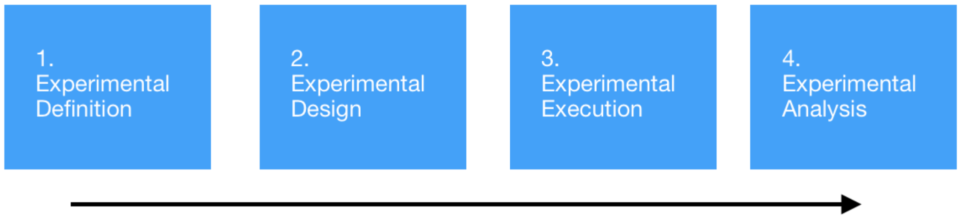

Figure 1: Experimental steps

1. Experimental Definition

   In the first phase of the experiment, fundamental aspects, in particular the research question and problem statement, are defined and recorded. This forms the basis for further planning and definition and hence determines the actual goal of the experiment.
   The definition phase is concluded with this proposal and the basic aspects are briefly summarized below.

   Motivation
   The motivation of this work is presented in the chapters 1 and 2.

   Object
   The object of the investigation is the effect of different representation variants of a vertically hierarchized UML statechart diagram from practice on model comprehension.

   Purpose
   The purpose of the study is defined in chapter 3.

2. Experimental Design

   In this phase, the experiment is planned and designed based on the former definition phase. Since the significance of the results depends to a large extent on the experimental design [21], this phase is of special importance.

   Regarding [21] the following questions have to be answered before the experiment can be performed:

   - What is going to be measured?
   - What are the dependent, independent and confounding variables?

- How are the independent variables manipulated?
- What is the material to be investigated?
- How are the dependent variables measured?
- What are threats to internal and external validity?
- What is the experimental setup?

What is going to be measured?
This question is already answered by the above definition of the object of investigation.

What are dependent, independent and confounding variables?
The independent variable in this experiment is the representation form of vertical hierarchization. It is investigated in three forms:

- Flat with cluster formation
- Sub-states on separate pages
- Self-developed representation

The first essential step of this work will be to develop an own representation of vertical hierarchization. As described in the problem statement, this should combine the advantages of the two other variants and at the same time keep the split-attention effect at a minimum.

What are dependent variables and how are they measured?
The main dependent variable is model comprehension. Prominent operationalizations involve the aspects of comprehension effectiveness and efficiency as given in [2]. In general, these variables are tested with a set of comprehension questions. During the preparation of the questionnaire, particular attention must be paid to the fact that some questions benefit from abstraction, while others being impaired by the split attention effect [4].

- *Effectiveness* is measured by the number of correct answers given by the participant. The underlying assumption is that more correct answers correspond to a better understanding.
- *Efficiency* is determined by dividing the effectiveness score by the time the participant took to answer the questions. This is done to avoid the processing time compromising comprehension effectiveness, as shorter processing time does not per se yield a better understanding.

An additional dependent variable is the *cognitive load (CL)*. Based on the CLT the CL is partitioned into intrinsic, extraneous and germane load. It will be measured by a questionnaire developed by Klepsch et al. [11]. CL provides an estimate for the mental effort resulting from the representation variants.

Since eye tracking is used as complementary measurement during the experiment sessions, additional variables will eventually be added.

What are confounding variables and how are they measured?

- Participants expertise in dealing with statecharts is expected to influence the dependent variables. Therefore, the expertise is measured seperately.

What is the material to be investigated?
A statechart model from the domain of rail vehicle platooning that emerged from a cooperation of the institute of software engineering and programming languages at Ulm University and partners form industry is used for investigation. This model will be adapted to achieve a similar complexity in terms of model elements and interrelations as given in [2] in order to ensure comparability.

What are the threats to internal validity?

- The expertise of the individual subjects in reading statecharts and in using the modeling tool may vary as both students from the university and staff of the institute of software engineering and programming languages at Ulm University participate in the study. However, in order to achieve a meaningful result, the participants are randomly distributed among the test groups according to [21]. In addition, the expertise is measured in a small practical test. Depending on the test result, the participants will undergo a short training session in order to secure a basic level of expertise.
- Since a more complex model is to be investigated, time problems may occur during the study. This factor is minimized by testing the procedure in a preliminary study and adapting the model accordingly. Furthermore, a between-group design is chosen for the experiment (see section below), whereby each respondent only has to work with one model.

What are the threats to external validity?

- Since this experiment considers only statecharts, the results and findings are limited to this area.
- Additionally, this work concentrates exclusively on vertical hierarchization. Therefore, no statement can be made as to whether another kind of hierarchization would yield other results.

What is the experimental setup?
According to [21] there are two design possibilities for this experiment. One is the between-group design and the other is the within-subject design. The within-subject design has two decisive disadvantages in this experiment. First, there is only a limited time window per participant and due to the complexity of the material, only one model can be examined. Secondly, to prevent a learning effect, three similarly complex models would have to be found for a within-subject design in order to investigate the three forms of representation. For these reasons, the between-group design is chosen for this experiment, even if this requires more subjects on average. Since there is only one independent variable with three manifestations, only three groups have to be formed and according to [21] 30 participants are sufficient in this case.
In summary, it can be said that some points of planning and design have already been dealt with. However, there are still some important aspects to be determined before the next phase. The first important step in this thesis will be to define the authors own representation. Therefore, further literature will be consulted, especially with regard to the split-attention effect. After the definition of the representation, the model has to be transformed into the three forms. Subsequently, the questions about the model are elaborated and a questionnaire is created which is used to measure the presented dependent variables. Finally, the procedure according to which the test persons are assigned to the respective groups is defined.

3. Experimental Execution

   Once the definition phase has been completed, the next step is the execution. In order to test the feasibility of the study conditions and to obtain further information on efficiency and methodology, a preliminary study is carried out. Following this and, if necessary, after an adaptation, the main study will be carried out. A complete implementation plan will be prepared in the course of the thesis. So far, the implementation plan will include an expertise test, the investigation of model comprehension accompanied by screen recording as well as eye tracking and a rating of the cognitive load of the representation variant.

4. Experimental Analysis

   In the last phase of the experiment, the collected data is statistically evaluated and interpreted. This is also done according to the specifications of [21]. The statistical evaluation includes the following four steps.

   a) First, it is determined whether the available data are parametric or non-parametric. This is decisive for the selection of the method used for the analysis [21].
   b) Next, it is determined whether the measured dependent variables correlate or not. This is also necessary for the selection of the statistical method.
   c) Determined by the two previous steps, the corresponding method is used for analysis.
   d) In the last step, the results obtained are interpreted and compared for the different forms of representation.

7 Limitations and Delimitations

The limitations arising from the threats to internal and external validity are already discussed in chapter 6.

One delimitation of this work is that only the effects of different representation variants are studied and other possible presentational factors that may also affect model comprehension, such as color cues, design patterns, layout algorithms are omitted. However, the examination of more independent variables would require more testing groups and thus a larger number of participants which would go beyond the time frame of this thesis.

8 Significance of the study

This work will on the one hand complement existing research on the effects of vertical hierarchization on model comprehension. On the other hand, it may also have the potential to expand already existing research in this area, as the self developed representation variant may result in a more efficient model understanding averaged over all types of question intents in the context of the model comprehension process.

Under the assumption that this work actually results in an efficient representation variant, this can also considerably influence model use in practice.

9 Planning

9.1 Own Background

The author of this thesis is currently a master student of software engineering at Ulm University. He has basic knowledge in dealing and working with statecharts as well as in UML modelling in general.

There is no experience in conducting an empirical study as well as in the field of eye tracking.

9.2 Required Resources

The following resources are required for this study:

1. An eye tracker (already available)
2. An expense allowance for the participants of the study
3. A room and the necessary equipment for the experimental setup
4. Employees of the institute as participants for the study

9.3 Work Packages

Figure 2 presents the general time schedule of this thesis consisting of six months M1 to M6. The thesis is divided into four phases. The expected time frame for each phase is represented as a beam. The details of each phase are briefly described below.

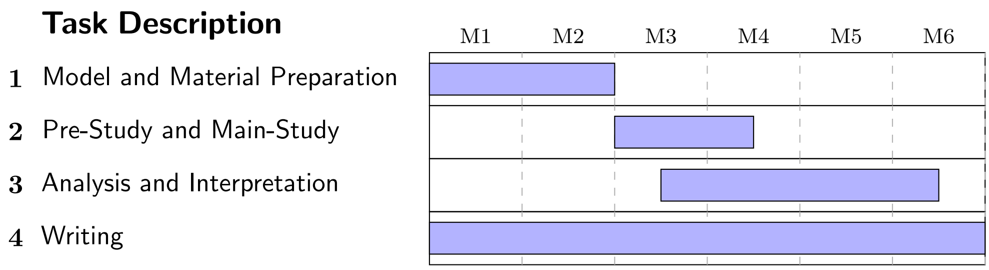

Figure 2: Thesis time schedule

Model and Material Preparation
In the first phase the author familiarizes himself with the given model as well as the editing tool. The first main task is to develop an own representation variant of the vertically hierarchized model. Afterwards, the model is transformed into the three representation forms and the comprehension questions are developed. In addition, the competency test and the CL-questionnaire are generated.

Pre-Study and Main-Study
This phase starts with a pre-study to test the experimental setup and time management. After possible adjustments, the main study is conducted.

Analysis and Interpretation
This phase consists of the analysis and interpretation of the data. Since encoding as a part of the analysis already starts during the execution of the main study, the second and third phases are overlapping. The steps executed to analyse the gathered data are described in section 6. The interpretation follows the guidelines of [21]

Writing
The last phase is the writing of the thesis. Since writing will be a consistent task over the complete time

period, this phase already starts at the beginning of the thesis.

9.4 Risks and Contingency plan

1. *Risk 1: Too few participants*
   If the minimum of 30 subjects [21] is not reached during the main study, a valid statistical analysis is problematic. The results may only be considered descriptively and understood as tendencies.

2. *Risk 2: Not enough time for analysis*
   If there is not enough time left to actually analyze the collected eye tracking data, the author will at least provide an implementation plan for future work.

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